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October 5, 2004

Docket No. 50-271
BVY 04-106
TAC No. MC0761

ATTN: Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Subject: **Vermont Yankee Nuclear Power Station**
Technical Specification Proposed Change No. 263 – Supplement No. 18
Extended Power Uprate – ECCS Pump Net Positive Suction Head Margin

References:

1) Entergy Nuclear Operations, Inc. letter to U.S. Nuclear Regulatory Commission, "Technical Specification Proposed Change No. 263 – Supplement No. 8, Extended Power Uprate – Response to Request for Additional Information," BVY 04-058, July 2, 2004

2) Entergy Nuclear Operations, Inc. letter to U.S. Nuclear Regulatory Commission, "Technical Specification Proposed Change No. 263 – Supplement No. 9, Extended Power Uprate – Revised Containment Overpressure Envelope," BVY 04-071, July 27, 2004

3) GE Nuclear Energy, "Safety Analysis Report for Vermont Yankee Nuclear Power Station Constant Pressure Power Uprate," NEDC-33090P (Proprietary), September 2003, and NEDO-33090 (Non-Proprietary), September 2003

Reference 1 provided a response to an NRC staff request for additional information (RAI) regarding the application by Entergy Nuclear Vermont Yankee, LLC and Entergy Nuclear Operations, Inc. (Entergy) for a license amendment to increase the maximum authorized power level of the Vermont Yankee Nuclear Power Station (VYNPS) from 1593 megawatts thermal (MWt) to 1912 MWt (i.e., an extended power uprate). Reference 2 updated certain information provided in Reference 1 regarding the revised containment overpressure analysis.

Attachment 1 to this letter provides Revision 8 of Calculation No. VYC-0808, "Core Spray and Residual Heat Removal Pump Net Positive Suction Head Margin Following a Loss of Coolant Accident and an Anticipated Transient Without Scram with Fibrous Debris on the Intake Strainers." An earlier version of this calculation was previously provided to the NRC staff in Reference 1 as Exhibit 1 to Attachment 4. Attachment 2 to Reference 2 provided Calculation Change Notice 06 to calculation VYC-0808. Revision 8 to VYC-0808 is the latest version of the calculation and incorporates changes made since the submittal of Reference 2 (Note: Revision 7 incorporated two change notices previously provided to the NRC staff.) These changes

A001

include a revised input assumption (i.e., condensate storage tank water temperature) and effects on suppression pool temperature associated with power uprate. Attachment 1 does not contain any proprietary information within the meaning of 10 CFR 2.390; disregard any "proprietary" markings.

The changed input assumption also slightly affected the results of the Anticipated Transients Without Scram (ATWS) analysis presented in Table 9-5 of Reference 3 (PUSAR):

- The value for peak suppression pool temperature under CPPU conditions increased from 190°F to 190.5°F.
- The value for peak containment pressure under CPPU conditions increased from 12.5 psig to 12.7 psig.

The results of the ATWS analysis are acceptable and continue to meet the acceptance criteria presented in PUSAR Section 9.3.1 of peak suppression pool temperature less than 281°F and peak containment pressure less than 62 psig.

This supplement to the license amendment request provides additional information to update Entergy's application for a license amendment and does not change the scope or conclusions in the original application, nor does it change Entergy's determination of no significant hazards consideration.

There are no new regulatory commitments contained in this submittal.

If you have any questions or require additional information, please contact Mr. James M. DeVincentis at (802) 258-4236.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on October 5, 2004.

Sincerely,

Jay K. Thayer

Jay K. Thayer
Site Vice President
Vermont Yankee Nuclear Power Station

Attachments (1)

cc: (see next page)

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Attachment 1

Vermont Yankee Nuclear Power Station

Proposed Technical Specification Change No. 263 – Supplement No. 18

Extended Power Uprate – Response to Request for Additional Information

ECCS Pump Net Positive Suction Head Margin

Calculation No. VYC-0808, Revision 8

Total number of pages in Attachment 1 (excluding this cover sheet) is 135.

CALCULATION COVER PAGE

☐ IP-2 ☐ IP-3 ☐ JAF ☐ PNPS ☒ VY

Calculation No. VYC-0808	This revision incorporates the following MERLIN DRNs or Minor Calc Changes: CCN04 and CCN06 to Rev. 6	Sheet 1 of 58

Title: Core Spray and Residual Heat Removal Pump Net Positive Suction Head Margin following a Loss of Coolant Accident and an Anticipated Transient Without Scram with Fibrous Debris on the Intake Strainers

☒ QR ☐ NQR

Discipline: Fluid Systems

Design Basis Calculation? ☒ Yes ☐ No

This calculation supersedes/voids calculation: Supercedes VYC-0808, Rev. 7 upon EPU implementation.

Modification No./Task No/ER No: VYDC 2003-008

☒ No software used

☐ Software used and filed separately (Include Computer Run Summary Sheet). If 'YES', Code:

☐ Software used and filed with this calculation. If 'YES', Code:

System No./Name: 10 RHR, 14 CS

Component No./Name: P-10-1A,B,C,D; P-46-1A,B

(Attach additional pages if necessary)

Print/Sign

REV #	STATUS (Prel, Pend, A, V, S)	PREPARER	REVIEWER/ DESIGN VERIFIER	OTHER REVIEWER/ DESIGN VERIFIER	APPROVER	DATE
7	A	B. C. Slifer	P.A.Rainey	None	J.G.Rogers	9/22/04
8	Pend	B. C. Slifer BC Slifer	P.A.Rainey P.A. Rainey	None	J.G.Rogers P.A. RAINEY FOR J.G. ROGERS PER TELECON P.A. Rainey	9/24/04

Sheet 1 of of 1

RECORD OF REVISIONS

Calculation Number: VYC-0808 **Page** 2 **of** 58

Revision No.	Description of Change	Reason For Change
7	1. Add, as an attachment, an evaluation of RHR pump NPSH margin in Shutdown Cooling mode. 2. Update Sections 3.2 and 4.2 to reflect current basis for debris and sludge terms and their effect on strainer head loss.	1. Incorporate CCN01. 2. Incorporate CCN03.
8	Changes reflect higher suppression pool temperatures associated with power uprate and the subsequent incorporation of containment overpressure credit in the calculation of NPSH margin.	Power uprate and incorporates CCN04 and CCN06 to VYC-0808 Rev. 6.

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3	Available NPSH for Most Limiting Torus Temperature Transient	10
4	RHR NPSH Margin in Shutdown Cooling Modes	16
5	Sulzer Bingham Pumps Inc. Document E12.5.561, NPSH/Minimum Flow Study-Summary Report, dated May 26, 1998.	19
6	Core Spray NPSH Evaluation	4
7	Residual Heat Removal (LPCI) NPSH Evaluation	12
8	EXCEL Verification	6
9	ATWS Sensitivity to CST Water Temperature Change	5

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1.0 OBJECTIVE

1.1 To determine the NPSH margin and containment overpressure required for the Core Spray and Residual Heat Removal (RHR) pump taking suction from the Torus (1) at maximum run out flow during the first 10 minutes following a LOCA, (2) at design flow at the maximum peak post-LOCA suppression pool temperature, and (3) over the long-term post-accident suppression pool heatup and cooldown transient. Attachment 4 also provides NPSH margin while in the shutdown cooling mode. 8

1.2 To determine the NPSH margin and containment overpressure required for the Core Spray and RHR pumps taking suction from the Torus following an Anticipated Transient Without Scram (ATWS) event. 8

1.3 Additionally, a basis for readily determining overpressure requirements, when performing RHR and CS pump NPSH evaluation for any other events which cause elevated suppression pool temperatures, will be provided. This will be in the form of a family of curves profiling overpressure required vs. pool temperature. 8

Revision 8 differs from Revision 7 by introducing the concept of overpressure credit for LOCA and ATWS, which was initially documented in CCN 4 to Rev. 6. Revision 8 also incorporates CCN 6 to Rev. 6 and changes to the LOCA and ATWS analysis which were issued after CCN 4 to Rev. 6 was accepted. Revision 8 will retain the status of PENDING until the license amendment for power uprate is approved, at which time the status will be changed to ACTIVE. 8

The RHR and Core Spray Systems are Safety Class 2.

2.0 METHOD OF SOLUTION

2.1 Required NPSH can be obtained from the pump curves based on witnessed tests performed by the pump vendor. There is a separate set of test data for each of the two Core Spray pumps and the four RHR pumps delivered to Vermont Yankee. A curve fit bounding the required NPSH data was developed for each pump type. The required NPSH for the RHR pumps is based on the data labeled "Minimum Operable NPSH @ Reduced Head". (The basis for the RHR required NPSH was reviewed during the AE Inspection (Ref. 4)).

At Vermont Yankee's request, the pump vendor performed additional NPSH evaluations for the RHR and Core Spray pumps in order to provide a more rigorous basis for interpolating between and extrapolating beyond the NPSH data base provided with the pumps. The pump vendor supplemented the data supplied for each pump with additional and more extensive data for the same or similar pumps obtained from their archives. The pump vendor used these data, adjusted as necessary using pump affinity laws, to develop characteristic NPSH curves that complement the original witnessed test data. When pumps have been NPSH tested over a small flow range and NPSH data are required outside of this range, the NPSH curves have to be extrapolated. Only NPSH tests of pumps of similar style, design, specific speed, suction specific speed, number of impeller vanes and suction vane angles can be used for this purpose.
The pump vendor also provided additional information to define allowable times of operation and minimum allowable NPSH for minimum flow conditions and at higher flow rates. The vendor report is included as Attachment 5.

2.1.1 RHR Pumps

The original witnessed test data for the four (4) RHR pumps covered a flow range of 6,300 gpm to slightly less than 9,000 gpm. This range is adequate for the RHR pumps since the expected maximum flow rates following a LOCA are between 7,100 gpm and 7,400 gpm.

NPSH tests were also performed on one of the four RHR pumps, prior to the final impeller trimming, at 6300, 8065, and 9502 gpm. Five (5) to eight (8) test points were taken at each of the above capacities to establish the slope and shape of NPSH vs. Total Dynamic Head (TDH) curve. These tests established that the so-called knee of the NPSH vs. TDH curve is gradual, i.e. there is no rapid drop in TDH for a relatively small reduction in NPSH. Data points were taken at TDH reductions of up to 8% relative to the values obtained at higher values of available NPSH. These data were used to develop a family of curves of NPSH vs. flow for TDH drops of 1%, 3%, and 6%. The witnessed test data compared to these curves fell somewhere between 3% and 6% lines, and slightly below the 6% line for flow rates above 7,000 gpm for the data points labeled "Minimum Operable NPSH @ Reduced Head". The vendor concluded that the pumps, if operated with the minimum NPSH, are within acceptable limits of the NPSH knee.

Extrapolation of required NPSH to flow rates less than 6,300 gpm was based on data from tests on similar pump designs, but of different sizes (18x24x28 CVIC and 8x10x21 CVIC vs. 16x18x26 CVIC). Similar pumps are of the same suction specific speed, number of vanes and suction vane angle. The extrapolation is based on estimation and experience from NPSH tests on other styles of pumps performed in recent years, when more detailed NPSH tests were required. NPSH at lower flow rates is of less importance than at higher flow rates since available NPSH will always be higher at lower flow rates because of lower head loss due to flow, and also since core and containment cooling requirements dictate flow rates higher than 6,300 gpm when reactor water level is below the elevation of the top of the active fuel. The extrapolated NPSH at flow rates less than 6,300 gpm is not used for the evaluation of design NPSH margins. The required NPSH at low flow rates is mainly of interest in evaluating operating characteristics under minimum flow conditions, when the pumps are operating with the minimum flow bypass valves in their open position until reactor pressure drops low enough to allow the injection valves to open.

The pump vendor also provided an assessment of the potential for permanent pump damage due to cavitation at the minimum NPSH. Their assessment required input from Vermont Yankee on the durations of operation at minimum NPSH conditions. Vermont Yankee provided this information in the form of predicted suppression pool temperature and available NPSH vs. time for the LOCA. Relative to the RHR pumps, when operating for seven (7) hours at 7,000 gpm with an available NPSH of 23 to 24 feet, the pump vendor concluded that, "Depending on water temperature and water chemistry there can be some "frosting (e.g. light pitting) on the impeller suction vanes, but there will be no detrimental pump damage due to cavitation when operating at minimum NPSH for the specified hours of operation." The vendor extended this assessment beyond the seven (7) hours at 23 to 24 feet of NPSH to define the NPSH required based on an impeller life of 8,000 hours. This information is compared to the expected decrease in suppression pool temperature following the peak, and subsequent increase in available NPSH, and it shows that the RHR pump will always operate within the acceptable bounds defined by the vendor.

The vendor recommended minimum flow requirements were given as $\leq$ 4 hours at 350 gpm and $\geq$ 4 hours at 2700 gpm. The corresponding required NPSH values were 30 ft at 350 gpm and 26 ft at 2700 gpm (page 5, Attachment 5).

2.1.2 CS Pumps

The original witnessed test data for the CS pumps covered a flow range of 3,000 gpm to slightly more than 3,800 gpm. The expected maximum flow rates following a LOCA are between 3,000 gpm and 4,600 gpm.

More comprehensive NPSH tests were performed on an identical pump for a different customer. These tests were performed at approximately 1780 rpm. Converted to 3582 rpm using affinity laws, the flow rates were 3005, 4037, 5038, 5120, 6000, 6020, and 6524 gpm, thus bounding the flow range of interest. Four (4) to ten (10) test points at each of the above capacities established the slope and shape of the NPSH vs. TDH characteristic curve. Differences in impeller trim diameter were also factored into the developed required NPSH curves. The vendor concluded that these tests were sufficient to develop NPSH characteristics for the pump and are representative of the pumps delivered to Vermont Yankee. The vendor also concluded that Vermont Yankee's pumps, if operated with the minimum NPSH, are within acceptable limits of the NPSH knee.

Extrapolation of required NPSH to flow rates less than 3,000 gpm was based on data from tests on similar pump design, but of different size (12x14x14 ½ CVDS and 14x16x23 CVDS vs. 12x16x14 CVDS). Similar pumps are of the same suction specific speed, number of vanes and suction vane angle. The extrapolation is based on estimation and experience from NPSH tests on other styles of pumps performed in recent years, when more detailed NPSH tests were required. NPSH at lower flow rates is of less importance than at higher flow rates since available NPSH will always be higher at lower flow rates because of lower head loss due to flow, and also since core cooling requirements dictate flow rates higher than 3,000 gpm when reactor water level is below the elevation of the top of the active fuel. The extrapolated NPSH at flow rates less than 3,000 gpm is not used for the evaluation of design NPSH margins. The required NPSH at low flow rates is mainly of interest in evaluating operating characteristics under minimum flow conditions, when the pumps are operating with the minimum flow bypass valves in their open position until reactor pressure drops low enough to allow the injection valves to open.

The pump vendor also provided an assessment of the potential for permanent pump damage due to cavitation at the minimum NPSH. Their assessment required input from Vermont Yankee on the durations of operation at minimum NPSH conditions. Vermont Yankee provided this information in the form of predicted suppression pool temperature and available NPSH vs. time for the LOCA. The vendor concluded that the CS pumps have more margin than the RHR pumps relative to potential damage from cavitation at the minimum available NPSH predicted for the LOCA. The vendor developed a curve of allowable hours of operation vs. available NPSH for the CS pump similar to that developed for the RHR pump. Comparison of predicted minimum available NPSH for the CS pumps vs. time for the LOCA shows that the CS pump will always operate within the acceptable bounds defined by the vendor based on an 8,000 hour impeller life.

The vendor recommended minimum flow requirements were given as ≤ 4 hours at 300 gpm and ≥ 4 hours at 1250 gpm. The corresponding required NPSH values were 32.5 ft at 300 gpm and 27 ft at 1250 gpm (page 5, Attachment 5).

2.2 Since the vendor chose to use a postulated minimum available NPSH rather than the minimum tested NPSH for their evaluation of acceptable durations of operation based on potential cavitation damage to the pump impeller, a reassessment of NPSH margins using minimum available NPSH rather than minimum tested NPSH was performed. The following table compares the values used in the vendors evaluations and comparable values at the same flow rates from the witness tests.

PUMP	FLOW (gpm)	Minimum Available NPSH assumed by Vendor for the Impeller Life Study (ft)	Minimum Required NPSH from Original Witness Tests[1] (ft)
CS	3,000	24.0	24.0
	4,600	28.0	No Data
RHR	6,400	23.0	23.2
	7,000	23.5	22.6
	7,600	24.0	23.5

Using the minimum available NPSH values from the impeller life study as required values is conservative since the values are based on the long-term reliability of the pump impellers, and they are equal to or bound the witnessed test data.

NPSH values at other flow rates are based on curve fits developed from the above data points and vendor predicted characteristic curves (NPSH vs. flow rate).

2.2.1 For CS, the curve fit incorporates the witnessed test data points for flow rates between 3,000 gpm and 4,600 gpm.

FLOW (gpm)	NPSH (ft)	SOURCE
3003	24.0	Curve No. 27692
3522	24.9	Curve No. 27692
3810	25.0	Curve No. 27692
3000	24.0	Curve No. 27691
3542	24.5	Curve No. 27691
3810	25.0	Curve No. 27691
4600	28.0	SBPI Document No. E12.5.561 (Attachment 5)

Curve Fit:

A following second order polynomial curve fit to conservatively bound the above data was developed:

$$NPSH = 26.4 - 2.965 \times 10^{-3} Q + 7.191 \times 10^{-7} Q^2$$

[1]NPSH is determined from a curve fit that bounds all data points for each pump.

where Q is Flow Rate in gpm.

Comparison between Data and Curve Fit

FLOW	DATA	FIT
3003	24.0	24.0
3500	none	24.8
3522	24.9	24.9
3810	25.0	25.5
4600	28.0	28.0

2.2.2 RHR

A different approach is taken for RHR. The witness test data were not used to develop a curve fit. The SBPI recommended minimum available NPSH bounded the Minimum Operable NPSH @ Reduced Flow data from the witness tests over the flow range of interest, therefore the recommended minimum available NPSH was used exclusively. A simple linear interpolation scheme is used as the curve fit.

Flow range: 6,400 gpm to 7,600 gpm

Sources: SBPI Document No. E12.5.561, NPSH/Minimum Flow Study-Summary Report, dated May 26, 1998. (Attachment 5)

Data:

FLOW	NPSH
6400	23.0
7000	23.5
7600	24.0

Curve Fit:

$$NPSH = 23.0 + (Q - 6400) / 1200$$

2.3 Available NPSH is calculated using the industry standard equation (Ref. 1)

$$\text{NPSH Available} = (p_{Torus} - p_v)(144)v + Z - H_f - H_d - H_s$$

where p_{Torus} = Torus pressure, psia

p_v = vapor pressure of the pumped fluid, psia

v = specific volume of the pumped fluid, cu ft / lb

Z = elevation head, torus to pump suction, ft

H_s = suction strainer loss, ft

H_d = strainer debris loss, ft

H_f = friction loss in suction piping, ft

2.4 The amount of debris on a strainer will vary with time, starting at zero and increasing to the total value as the debris passes through each strainer and is removed from the water. Assuming the debris is uniformly dispersed in the suppression pool, the fraction of debris deposited on the strainers at a time, t, after initiation of flow, assuming a constant flow rate, is (see Attachment 1 for the derivation)

$$D/D_{total} = (1 - e^{-Qt/V})$$

where D/D_{total} = fraction of the total debris deposited on the strainer
Q = total pump flow rate
t = time
V = suppression pool volume = 68,000 cu ft minimum (TS 3.7.A.1.e)

This equation is used to determine the amount of fibrous debris deposited on the strainers during the first 10 minutes following a LOCA.

After ten minutes, it is assumed that one Core Spray pump provides cooling to the core, and one RHR pump cools the suppression pool. The remaining debris in the suppression pool and any debris deposited on an active strainer supplying pump(s) in the short-term that is subsequently secured for the long-term is deposited on the two active strainers in proportion to their flow rates. The total debris thus deposited on the two active strainers is used to determine NPSH margin at the peak suppression pool temperature.

2.5 A survey of ECCS single failures was done to identify what single failure resulted in the maximum debris accumulation on the strainers during the first ten minutes and at the peak suppression pool temperature.

3.0 INPUTS AND ASSUMPTIONS

3.1 The suppression pool temperatures used in the analysis are based on ~~Reference 19~~ General Electric Company calculations for LOCA and ATWS (Ref. 10 and Ref. 11). 8

3.2 The debris head loss term for the RHR and Core Spray strainers is based on the DBA LOCA Base Case documented in VYC-1924, Rev. 0 (Ref. 2). 8

RHR @ 7400 gpm	0.33 ft	RHR @ 14200 gpm	0.48 ft
CS @ 3500 gpm	0.21 ft	CS @ 4600 gpm	0.32 ft

These head loss values are based on debris loads that are different than those calculated in VYC-1677 (Reference 3), and on a peak suppression pool temperature that is less than calculated in Reference 10. Both of these effects cause a slightly higher calculated head loss, and thus represent additional conservatism in the calculation. The degree of conservatism is indicated in the "Revised ECCS Suction Strainer Head Loss Assessment for Vermont Yankee" (Attachment 2). The calculation of NPSH margin is done at the peak LOCA suppression pool temperatures because the negative effect of vapor pressure on NPSH margin significantly outweighs the slight benefit on the debris head loss term. 8

As documented in ERC No. 2003-027 (Ref. 12), EPU does not affect the debris source terms.

It should be noted that the limiting head loss due to debris loading on the RHR and CS suction strainers is calculated at a specific temperature. Strainer head loss is essentially inversely proportional to fluid temperature as documented in the sensitivity evaluation in VYC-1924 Rev 0 (Ref. 2). Therefore the calculated limiting head loss, described above, will be conservatively used for all fluid temperatures greater than or equal to that used in the calculation of the limiting head loss. For lower temperatures, the head loss will be increased in proportion to the decrease in temperature. 8

3.3 ~~The calculation also conservatively assumes that containment pressure is equal to 14.7 psia regardless of the temperature and the initial pressure. This assumption is in accordance with Regulatory Guide 1.1.~~Note that prior revisions of this calculation assumed torus pressure remains at atmospheric pressure in the evaluation of NPSHa. However, because of the increased pool temperature at power uprate conditions and resulting increased vapor pressure, there will not be adequate NPSHa for some events without taking credit for some torus air space pressure. If NPSHa is inadequate, then the necessary torus air space pressure, above atmospheric pressure, (overpressure) will be calculated to yield adequate NPSHa. Containment overpressure required and available is determined in accordance with Regulatory Guide 1.82, Rev. 3. For a high temperature, time dependent event, such as a LOCA, the NPSH will be evaluated over the time-temperature profile of the event in lieu of just at the maximum temperature. This will allow development of a time dependent profile for required overpressure. The amount of overpressure credited in the evaluation of margin is based on engineering judgment and is selected to be approximately half-way between the overpressure required and the overpressure available. 8

3.4 The LOCA calculation is done for two conditions called short-term and long-term. 8

3.4.1 The short-term condition assumes that the suppression pool temperature is at its highest calculated value at 10 minutes, and there has been no operator action to initiate suppression pool cooling or to secure or throttle ECCS pumps. Reactor pressure is assumed to be equal to containment pressure, thus ECCS pumps are operating at their maximum flow rates. ~~The maximum suppression pool temperature at the end of 10 minutes is assumed to be 164°F (page 2, Ref. 19).~~ The debris loading on the ECCS pump suction strainers is based on the maximum fraction of the suppression pool volume that 8 has passed through the strainers during the first 10 minutes of the event. The maximum run out flow for the one RHR pump is 7,400 gpm in one loop, for two RHR pumps in one loop, 14,200 gpm, and for the Core Spray pump, 4,600 gpm (Ref. 7).

3.4.2 The long-term condition is assumed to be anytime after the first 10 minutes ~~represent the conditions when the peak suppression pool temperature is reached, several hours after~~ 8 ~~initiation of the LOCA. The peak suppression pool temperature is assumed to be 182.6°F (Table 2, Ref. 19). The peak temperatures were selected to bound both short- and long-term conditions.~~ It is assumed that the ECCS suction strainers have reached their maximum debris loadings by the time the suppression pool reaches its peak temperature. It is also assumed that, in accordance with operating procedures (Ref. 8), operators have initiated torus cooling with the RHR. ~~Previous calculations of NPSH for the RHR assumed that the RHR flow would be throttled to 7,000 gpm, per procedures. In~~ 8 ~~anticipation of a potential change which will eliminate the 7,000 gpm limit on flow, t~~The present calculation ~~will~~ assumes an RHR flow rate of 7,400 gpm, which is the maximum short-term flow rate for one RHR pump in the LPCI mode (see Section 3.3). The actual flow rate is expected to be less than 7,400 gpm.

The Core Spray pump is assumed to be throttled based on Emergency Operating Procedures. Operators will monitor NPSH limit curves in the EOPs and will throttle flow if indicated flow and pool temperature are outside the acceptable operating envelope. In order to assure adequate core cooling, a minimum indicated flow rate of 3,244 gpm will be maintained (Ref. 20). A minimum indicated flow rate of 3,244 gpm could result in a maximum actual flow rate of 3,500 gpm, allowing about 100 gpm for an operator tolerance band and worst case flow instrument uncertainty (Table 10, Ref. 21).

3.5 The elevation head, Z, is based on the calculated suppression pool~~torus~~ volume ~~at 10 minutes and at the peak pool temperature from VYC-1628 (Run 3, Ref. 23), and the relationship between volume and level from VYC-1254, Rev. 3 (Ref. 24)~~from Revision 8 7. This term was not revised for power uprate. The corresponding pool volumes from the power uprate analysis are slightly higher than the values used in the calculation. Therefore, the use of the current elevations is conservative. The pool volumes ~~from Ref. 23~~ do not include the volume of water in the downcomers. Therefore, the appropriate relationship between level and volume in Ref. 24 is from Table 4.3-1 using the volumes from the column labeled "downcomers empty". The constants are the elevation of the suction datum for the Core Spray and RHR pumps.

The elevation head, Z, is the difference between the elevation of the suppression pool surface and the pump suction. Key dimensions from Dwg. 6202-1 (Ref. 13):

Torus Centerline Elevation	230 ft 1.5 in
Torus I.D.	27 ft 8 in

Therefore, elevation of torus invert = 230' 1.5" - 1/2 (27' 8") = 216' 3.5", or 216.29 ft.

	Pool Volume	Torus Water Level	Torus Water Elevation
Short-term	76,800 ft^3	11.93 ft	228.22 ft
Long-term	77,640 ft^3	12.03 ft	228.32 ft

The corresponding pool volumes under uprate conditions are 79,390 ft^3 (short-term, at 600 seconds) and 79,620 ft^3 (long-term, at the time of the peak pool temperature) (Ref. 10). 8

Core Spray pump suction center line	215' 9" (215.75 ft)	Ref. 25
RHR pump suction center line	215' 11" (215.92 ft)	Ref. 26

Therefore, Z for Core Spray and RHR,

	Core Spray	RHR
Short-term	12.47 ft	12.30 ft
Long-term	12.57 ft	12.40 ft

3.6 The strainer head loss is based on the vendor calculated values for the clean strainer and fittings (Ref. 6).

RHR	Core Spray
0.33 ft @ 7400 gpm	0.38 ft @ 4000 gpm
1.22 ft @ 14200 gpm	0.51 ft @ 4600 gpm

At flow rates less than 4000 gpm for Core Spray, the head loss is adjusted by the square of the ratio of the flow rate to the reference value, thus $H_s = 0.38\ (Q/4000)^2$.

3.7 The head loss in the suction piping from the torus to the pumps is based on the calculations in Attachment 6 for Core Spray and Attachment 7 for RHR. These calculations are adjusted here to remove the terms for the old strainer tees and other fittings associated with the strainers inside the torus since the guaranteed head loss term for the new strainers includes those fittings already, therefore the adjusted values will represent only the piping runs and fittings from the new strainer to the pumps.

Friction and form losses in suction piping, including the old strainer tee entrance, are from Attachment 6 for Core Spray. From p. 3 of Attachment 6, the L/D for the "strainer entrance tee" was given as 30. The total L/D for all fittings was 132. Deducting the strainer entrance tee leaves a revised total L/D of 102. The total equivalent length of 12" (STD) pipe is 102 ft plus 35 ft for the pipe run (from p. 2 of Attachment 6), or 137 ft. This length is then adjusted to 12" Schedule 40 pipe by multiplying by 0.974 (p. 4, Attachment 6), thus 137 ft x 0.974 = 133 ft. of 12" Schedule 40 equivalent. The head loss for 3000 gpm is, from p. 4, Attachment 6,

$$H_{fCS} = 133 \text{ ft } (0.731 \text{ psi/100 ft}) (2.31 \text{ ft/psi}) = 2.25 \text{ ft @ } 3000 \text{ gpm}$$

or, generalizing,

$$H_{fCS} = 2.25\ (Q/3000)^2 = 2.5 \times 10^{-7}\ Q_{CS}^2$$

For RHR, friction and form losses in suction piping, including the old strainer tee entrance, are from Attachment 7. From p. 3 of Attachment 7, the L/D for the "strainer entrance tee" and "Miter Bend" was given as 119 and 6, respectively, in terms of 24" STD pipe. The total L/D for all fittings was 153. Deducting the strainer entrance tee and miter bend leaves a revised total L/D of 28. Converting to the equivalent length of 24" STD pipe,

$$L_{24"} = (28)(23.25"/12"/\text{ft}) = 54.25 \text{ ft}$$

This value is added to the 8.73 ft of piping run from p. 2, Attachment 7, for a total length of 62.98 ft. Attachment 7 next adjusted pipe lengths to an equivalent length of 20" Schedule 40 pipe using an equivalent pressure drop basis. The conversion factor is 0.347 from p. 3 of Attachment 7, thus

$$L_{20"Sch40} = 0.347\ (62.98\ \text{ft}) = 21.85\ \text{ft}.$$

This value is next added to the equivalent length of 26" pipe in terms of 20"Schedule 40, which is 39.90 ft (p.5, Attachment 7). Thus, the total equivalent length of 20"Schedule 40 pipe from the torus to the tee connection to the RHR pumps is 21.85 + 39.90 = 61.75 ft, excluding the old strainer tee and miter bend. This value can be carried through the remainder of the calculations in Attachment 7, and arrive at the following expressions for single pump and two pump operation.

For single pump operation, refer to p. 11, Attachment 7,

$$H_{f,1RHR} = 4.77 \times 10^{-8}\ Q^2$$

For two pump operation, refer to p. 12, Attachment 7,

$$H_{f,2RHR} = 7.836 \times 10^{-8}\ Q^2$$

where Q in both cases refers to RHR pump flow per pump in gpm.

3.8 The RHR flow rate evaluated for ATWS is not specified in GE Task Report T0902 (Ref. 11). The analyzed flow rate is conservatively taken as 7400 gpm for one RHR pump. These are the same flows rates used for the LOCA evaluation. Suctions losses and strainer losses are conservatively larger with larger flow rates. 8

4.0 CALCULATION

4.1 Debris Accumulation

4.1.1 The following ECCS combinations, based on single failure (including none), were considered in determining short-term debris accumulation (the use of the designations "A" and "B" is arbitrary).

Single Failure	No. of CS Pumps	No. of RHR Pumps, Loop A	No. of RHR Pumps, Loop B	No. of Active Suction Sites, N_s
Diesel Generator	1	1	1	3
CS Pump/Injection Valve	1	2	2	3
LPCI Injection Valve	2	2	0	3
RHR Pump	2	2	1	4
None	2	2	2	4

4.1.2 The run out flow rates, per pump, using the values from Paragraph 3.4,

Single Failure	CS A	CS B	RHR per pump Loop A	Total RHR, Loop A	RHR per pump Loop B	Total RHR, Loop B
Diesel Generator	4,600	0	7,400	7,400	7,400	7,400
CS Pump/Injection Valve	4,600	0	7,100	14,200	7,100	14,200
LPCI Injection Valve	4,600	4,600	7,100	14,200	0	0
RHR Pump	4,600	4,600	7,100	14,200	7,400	7,400
None	4,600	4,600	7,100	14,200	7,100	14200

4.1.3 The total flow rate from the suppression pool to the reactor vessel, and the debris fraction at ten minutes, using the equation from Paragraph 2.4,

Single Failure	Total Flow Rate, Q	$D/D_{total} = (1 - e^{-Qt/V})$ t=10 min V=68,000 ft^3 x 7.48 gal/ft^3
Diesel Generator	4,600+7,400+7,400=19,400	0.317
CS Pump/Injection Valve	4,600+14,200+14,200=33,000	0.477
LPCI Injection Valve	9,200+14,200=23,400	0.369
RHR Pump	9,200+14,200+7,400=30,800	0.454
None	9,200+14,200+14,200=37,600	0.522

4.1.4 After 10 minutes, all but one Core Spray pump and one RHR pump are assumed to be secured. In addition, the Core Spray pump is assumed to be throttled to 3500 gpm. The distribution of debris on the one active CS strainer and the one active RHR strainer will be the amount initially deposited in the short-term, plus the amount redistributed from the now-inactive strainer(s), plus the amount not removed in the short-term. The distribution of the remaining amounts will be in proportion to the CS and RHR flow rates. The results are summarized below.

Single Failure		CS A	CS B	RHR A	RHR B	Total
Diesel Generator	Short Term Flow Rate	4600	0	7400	7400	19400
	Short Term Accumulation	0.075	0.000	0.121	0.121	0.317
	Long Term Flow Rate	3500	0	7400	0	10900
	Redistributed	0.000	0.000	0.000	0.121	0.121
	Long Term Accumulation	0.333	0.000	0.667	0.000	1.000
CS Pump/Inj. Valve	Short Term Flow Rate	4600	0	14200	14200	33000
	Short Term Accumulation	0.066	0.000	0.205	0.205	0.477
	Long Term Flow Rate	3500	0	7400	0	10900
	Redistributed	0.000	0.000	0.000	0.205	0.205
	Long Term Accumulation	0.300	0.000	0.700	0.000	1.000
LPCI Inj. Valve	Short Term Flow Rate	4600	4600	14200	0	23400
	Short Term Accumulation	0.073	0.073	0.224	0.000	0.369
	Long Term Flow Rate	3500	0	7400	0	10900
	Redistributed	0.000	0.073	0.000	0.000	0.073
	Long Term Accumulation	0.298	0.000	0.702	0.000	1.000
RHR Pump	Short Term Flow Rate	4600	4600	14200	7400	30800

	Short Term Accumulation	0.068	0.068	0.209	0.109	0.454
	Long Term Flow Rate	3500	0	7400	0	10900
	Redistributed	0.000	0.068	0.000	0.109	0.177
	Long Term Accumulation	0.300	0.000	0.700	0.000	1.000
None	Short Term Flow Rate	4600	4600	14200	14200	37600
	Short Term Accumulation	0.064	0.064	0.197	0.197	0.522
	Long Term Flow Rate	3500	0	7400	0	10900
	Redistributed	0.000	0.064	0.000	0.197	0.261
	Long Term Accumulation	0.301	0.000	0.699	0.000	1.000

The above information was used to determine the distribution of each of the various debris species postulated to be deposited in the suppression pool following a LOCA (Ref. 3). However, the above distributions were not used to determine the head loss due to debris used in this calculation as discussed below. The above distributions were used as input to VYC-1677 (Ref. 3), and the resulting debris loads were used to assess the head loss due to debris shown in Attachment 2.

4.2 Head Loss due to Debris

The maximum predicted head loss for the CS and RHR strainers are based on the vendor calculations (Ref. 2), using conservative debris loads, fluid temperatures, and flow rates. These were discussed in Section 3.2 as Inputs and Assumptions. The head losses so determined are shown in Attachment 2 to be conservative relative to updated information on debris distribution (Section 4.1), debris loads (Ref. 3), flow rates and fluid temperatures. Attachment 2 has not been adopted as the design basis because additional assessments are ongoing regarding the time interval for torus cleaning, which may affect the final specification of the "sludge" term in the head loss calculation.

4.3 NPSH Margin

4.3.1 LOCA – Short Term

The temperature and pressure (T/P) profile for the suppression pool during a LOCA is developed in GE-VYNPS-AEP-346, Rev. 2 (Ref. 10). The short term data is provided from 0-600 seconds.

The evaluation of NPSH is documented in Table 4.1 using the peak pool temperature of 165.1°F which occurs at 600 seconds with a corresponding pool pressure of 17.64 psia. The peak temperature results in the largest vapor pressure and lowest NPSHa. Note that the temperature at lowest pool pressure is 161.2°F / 17.40 psia. At this temperature the gain in vapor pressure more than offsets the reduction in pool pressure, therefore the 165.1°F case governs. The details of the evaluation are presented at the top of the Table followed by a matrix of the NPSH results for CS and RHR. Further discussion of selected terms is presented below. 8

Suction Elevation Head, Z

The values of Z for RHR and CS (12.30' and 12.47'respectively) as calculated in Section 3.5 are conservatively used in this evaluation. The suction elevation head is based on the water elevation in the torus. The EPU suppression pool water volume is slightly larger than the value used in Section 3.5, which would result in a slight increase in water elevation, and therefore Z is conservative.

A water volume comparison at 600 seconds is provided below:

	Pre-EPU	EPU
Ref.	(Section 3.5)	(Ref. 10)
Short Term	76,800 cuft	79,390 cuft

8

Maximum Debris Losses (hd)

1 RHR: The head loss is taken as 0.33 ft at 173°F is used. (Case 1 of Tables 2 and 8 of Ref. 2).

2 RHR: The head loss is taken as 0.48 ft at 170°F (Case 2b of Tables 2 and 8 of Ref. 2) and 14200 gpm.

CS The head loss is conservatively taken as 0.32 ft at 173°F (Case 3d of Tables 2 and 8 of Ref. 2) and 4600 gpm.

Refer to Section 3.2 for application of head loss at temperatures other than those used in its calculation.

NPSHr - CS

Figure 2.2-1 of Attachment 3 provides a plot of *Allowable Operating Periods @ NPSHa Specified* values for various flow rates. This plot shows that at 4600 gpm an allowable NPSH of 28.0 ft is acceptable between 0 and 7 hrs of operation.

NPSHr - 1 RHR

Figure 2.1-1 of Attachment 3 provides a plot of *Allowable Operating Periods @ NPSHa Specified* values for various flow rates. This plot shows that at 7400 gpm an allowable NPSH of 23.8 ft is acceptable between 0 and 7 hrs of operation.

NPSHr - 2 RHR

With two RHR pumps operating at a total flow of 14,200 gpm this yields a flow of 7100 gpm per pump.

Also per Figure 2.1-1 of Attachment 3, the plot shows that at between 0 and 7 hrs of operation, an allowable NPSH of 23.5 ft is acceptable at 7000 gpm and 24.0 ft is acceptable at 7600 gpm.

Interpolating between plotted NPSH values of 23.5 ft @ 7000 gpm and 24.0 ft @ 7600 gpm yields 23.6 ft @ 7100 gpm.

The interpolation equation is developed as documented Section 2.2.2 and is 23.0+(Q-6400)/1200 8

Evaluation
As can been seen from Table 4.1, there is adequate NPSHa and overpressure is not required.

4.3.2 LOCA – Long Term

The temperature and pressure (T/P) profile for the suppression pool during a LOCA is developed in GE-VYNPS-AEP-346, Rev. 2 (Ref. 10). The long term data is provided from 0-864,000 seconds.

The evaluation of NPSH is documented in Table 4.2 using a selected T/P points representing the long term profile of the suppression pool. The details of the evaluation are presented at the top of the Table followed by a matrix of the NPSH results for the T/P profile of CS and RHR. The evaluated long term flow rates of 7400 gpm (RHR) and 3500 gpm (CS) are per Section 3.4.2. Further discussion of selected terms is presented below.

Suction Elevation Head, Z

The values of Z for RHR and CS (12.40' and 12.57' respectively) as calculated in Section 3 are conservatively used in the evaluation. The suction elevation head is based on the water elevation in the torus. The EPU suppression pool water volume is slightly larger than the value used in Section 3.5, which would result in a slight increase in water elevation, and therefore Z is conservative.

A water volume comparison at maximum pool temperature is provided below:

	Pre-EPU	EPU
Ref.	(Section 3.5)	(Ref. 10)
Long term	77,640 cu ft	79,620 cu ft

Maximum Debris Losses (hd)

1 RHR: Refer to Section 4.1.

CS 0.21 ft at 173°F is used. This is based on a conservative CS flow rate of 4000 gpm. (Case 3b of Tables 2 and 8 of Ref. 2).

8

NPSHr - CS

Figure 2.2-1 of Attachment 3 provides a plot of *Allowable Operating Periods @ NPSHa Specified* values for various flow rates. This plot shows that at 3500 gpm the allowable NPSH increases between 7 and 20 hrs of operation and a value of 29.6 ft is acceptable beyond 20 hrs of operation. This maximum value is conservatively used for the entire long term period (>600 sec).

NPSHr - RHR

Figure 2.1-1 of Attachment 3 provides a plot of *Allowable Operating Periods @ NPSHa Specified* values for various flow rates. This plot shows that at 7400 gpm the allowable NPSH increases between 7 and 100 hrs of operation and a value of 31.7 ft is acceptable beyond 100 hrs of operation. This maximum value is conservatively used for the entire long term period (>600 sec).

Evaluation
As can been seen from Figure 4.2 the overpressure required for RHR envelopes that required for CS and the overpressure varies continuously over time. In order to facilitate reporting and presentation of the overpressure required, an enveloping, stepped, overpressure credit is overlaid on Figure 4.2. The basis for overpressure credit is discussed in Section 3.3.

Though the long term flow rates are postulated at time 600 seconds (e.g. CS throttled down from 4600gpm to 3500gpm), it is not the intent of this calculation to imply at what time throttling should commence or how much throttling is required. This is a function of the time dependent NPSHr and pool temperature. This calculation conservatively evaluates the maximum NPSHr as occurring over the entire operating period (>600 sec). The actual NPSHr is lower between 0-7 hrs and increases after 7 hrs.

Note that Section 4.3.4 develops required overpressure for both the CS and RHR pumps as a function of flow, temperature and NPSHr without any debris loading. Refer to Table 4.4 and Figures 4.4-1 to 4.4-4. 8

4.3.3 ATWS

Note that NPSH evaluation of the ATWS event was not previously addressed by calculation VYC-0808. The temperature and pressure (T/P) profile for the suppression pool during the ATWS events is developed in GE-Task Report T0902 (Ref. 11). A sensitivity study on the effects of condensate storage tank water temperature (Attachment 9) has been done and the effects of an increase in CST temperature on NPSH are addressed in this section.

The evaluated events are MSIVC and PRFO with the peak temperatures and corresponding pressures tabulated by GE in Section 3.3.1.2 of the Task Report. Selected data points are extracted from the included T/P profile plots, Figures 3-10 and 3-12 of the Task Report, and are shown below. The two events have essentially the same temperature pressure profile. For convenience, these are combined into one enveloping event with maximum temperatures and minimum pressure at each time step.

MSIVC			PRFO			Combined		
Time, sec	Temp, °F	Press, psig	Time, sec	Temp, °F	Press, psig	Time, sec	Temp, °F	Press, psig
0	90	0	0	90	0	0	90	0
300	160	6.3	300	157	6.3	300	160	6.3
600	175	8.8	600	168	8.2	600	175	8.2
1000	182	11.2	1000	180	10.7	1000	182	10.7
1300	187	11.5	1300	187	11.8	1300	187	11.5
1724	189	12.3	1838	190	12.5	1838	190	12.3
3000	186	11.9	3000	187	12.1	3000	187	11.9
5000	182	11.2	5000	182	11.3	5000	182	11.2
6000	180	10.8	6000	180	11.0	6000	180	10.8
8000	175	10.0	8000	175	10.2	8000	175	10.0

As documented in T0902, Section 3.2.11 and 3.2.2.2, the suppression pool cooling is based on two loops of RHR operating and an initial pool volume of 68,000 cuft. Note that CS does not operate for ATWS events. 8

The evaluation of RHR pump NPSH is documented in Table 4.3 for the minimum NPSHr (0-7 hrs) The details of the evaluation are presented at the top of the Table followed by a matrix of the NPSH results for RHR. Further discussion of selected terms is presented below.

Since there are no data points available beyond 8000 seconds, margins at intermediate NPSHr (7hrs – 20hrs) and maximum NPSHr (20hrs – 100hrs) were not evaluated. However, since both RHR loops are available and assumed to be in operation, suppression pool temperatures will continue to drop beyond 8000 seconds and available NPSH will correspondingly increase as suppression pool temperature decreases.

Flow rate – Q (gpm)

The RHR flow rate is assumed to be at the maximum value assumed in the LOCA analysis, i.e. 7400 gpm. Refer to Section 3.8.

Suction Elevation Head, Z

The suppression pool volume addressed in the GE report is 68,000 ft^3. As noted in Section 3.5 the relationship between suppression pool volume and level is documented in Table 4.3-1 of Calc VYC-1254 Rev 3 (Ref. 24). .The suppression pool level corresponding to 68,000 ft^3 is 10.88'from VYC-1254.

This water level is 1.05' less than (11.93'-10.88') that used for calculating the RHR short term Z (12.30') in Section 3.5. Therefore the adjusted Z for the ATWS evaluation is 12.3'-1.05' = 11.25'.

Maximum Debris Losses (hd)

This term is not directly applicable for ATWS since there is no high-energy line break (HELB) to dislodge insulation and create debris in the suppression pool. However, there is sufficient margin to accommodate the design basis debris head loss of 0.33 ft for RHR and the evaluation is done accordingly.

8

Minimum NPSHr - 1 RHR (<7hrs)

Refer to Section 4.3.1.

Evaluation Minimum NPSHr (<7 hrs)

As can been seen from Table 4.3, overpressure is required from about 1000 to 3000 seconds. An overpressure of 1.27 psig is required to accommodate the peak pool temperature of 190°F at 1838 seconds. A plot of the overpressure required is shown in Figure 4.3-1. Note that for the same time period, this overpressure required is bounded by that required for LOCA.

The sensitivity study for the effect of increased CST temperature estimated a maximum increase of 0.5 °F on peak pool temperature and no more than 0.2 psi in pressure (Attachment 9). Table 4.3 shows that these changes will result in an increase in the overpressure required from 1.27 psig to 1.37 psig. This is well within the overpressure available of 12.3 to 12.5 psig, and below the 2.4 psig overpressure credit requested for LOCA at the time of the peak temperature.

Note that long-term LOCA suppression pool temperatures are higher than ATWS (Figure 4.3-2). Suppression pool temperature drops relatively soon after the peak occurs at 1838 seconds. RHR pump available NPSH will continue to increase as pool temperature drops and is clearly bounded by LOCA, therefore there is no need to do a long-term NPSH evaluation for ATWS.

4.3.4 General Profile – Overpressure Required vs Pool Temperature

A wide temperature range is evaluated, up to 205°F, which is about 10°F more than the peak LOCA temperature addressed by GE-VYNPS-AEP-346, Rev. 2 (Ref. 10).

The NPSH evaluation of general overpressure requirements for the RHR and CS pumps is documented in Table 4.4 for the minimum NPSHr (0-7 hours of operation) and maximum NPSHr (>7 hours of operation). The details of the evaluation are presented at the top of the Table followed by a matrix of the NPSH results. Further discussion of selected terms is presented below.

Flow rates – Q (gpm) - RHR

1 RHR: 7400 and 7000*gpm

2 RHR: 14,200 gpm (7100 gpm each) and 12,800 gpm (6400* gpm each)

* these values are conveniently selected, based upon the pump vendor's data, for the purpose of establishing a profile range.

8

Flow rates – Q (gpm) - CS

CS: 4600 gpm and 3500 gpm

Suction Elevation Head, Z

Based on a minimum suppression pool volume of 68,000 ft^3.

RHR: 11.25' as calculated in Section 4.3.3.

CS: 11.42' based on the evaluation documented in Section 4.3.3 and adjusting for the CS short term Z (12.47'). Therefore the adjusted Z is 12.47'-1.05' = 11.42'.

Clean Strainer Losses (hs)

Refer to Section 3.6

1 RHR @ 7400 gpm = 0.33'

1 RHR @ 7000 gpm = 0.30' = 0.33*(Q/7400)^2**

2 RHR @ 14,200 gpm (7100 each) = 1.22'

2 RHR @ 12,800 gpm (6400 each) = 0.99' = 1.22*(Q/14200)^2**

** head loss at other than the reference flow rate is proportional to the square of the flow ratio

CS @ 4600 gpm = 0.51'

CS @ 3500 gpm = 0.29 = 0.38*(Q/4000)^2

Maximum Debris Losses (hd)

This term is not applicable since no high-energy line break (HELB) is postulated to dislodge insulation and create debris in the suppression pool.

Minimum NPSHr

1 RHR @ 7400 gpm = 23.8' Refer to Section 4.3.1

1 RHR @ 7000 gpm = 23.5' Refer to Section 4.3.1

2 RHR @ 7100 gpm (each) = 23.6' Refer to Section 4.3.1 8

2 RHR @ 6400 gpm (each) = 23.0' (see below)

Figure 2.1-1 of Attachment 3 provides a plot of *Allowable Operating Periods @ NPSHa Specified* values for various flow rates. This plot shows that at 6400 gpm an allowable NPSH of 23.0 ft is acceptable for less than 7 hrs of operation.

CS @ 4600 gpm = 28.0' Refer to Section 4.3.1

CS @ 3500 gpm = 24.8' (see below)

Figure 2.2-1 of Attachment 3 to provides a plot of *Allowable Operating Periods @ NPSHa Specified* values for various flow rates. This plot shows that at 3500 gpm an allowable NPSH of 24.8 ft is acceptable for less than 7 hrs of operation.

<u>Maximum NPSHr</u>

1 RHR @ 7400 gpm = 31.7' Refer to Section 4.3.2

1 RHR @ 7000 gpm = 29.5' Refer to Section 4.3.3

2 RHR @ 7100 gpm (each) = 30.0' Refer to Section 4.3.3

2 RHR @ 6400 gpm (each) = 28.5' (see below)

Figure 2.1-1 of Attachment 3 provides a plot of *Allowable Operating Periods @ NPSHa Specified* values for various flow rates. This plot shows that at 6400 gpm an allowable NPSH of 28.5 ft is acceptable at greater than 100 hrs of operation. 8

CS @ 4600 gpm = 35.0' (see below)

CS @ 3500 gpm = 29.6' Refer to Section 4.3.2

Figure 2.2-1 of Attachment 3 provides a plot of *Allowable Operating Periods @ NPSHa Specified* values for various flow rates. This plot shows that at 4600 gpm an allowable NPSH of 35.0 ft is acceptable at greater than 100 hrs of operation.

~~The Table 1 summarizes the calculated available NPSH at the flow rates and temperatures of interest for a clean strainer. The calculations were done for the design basis flow rates and maximum short-term and long-term temperatures. Other temperature points were calculated to show the sensitivity of the results. The available NPSH is compared to the required NPSH, and if the margin is greater than the maximum head loss due to debris, then it can be concluded that post-accident performance is acceptable at the design basis points.~~ 8

Table 4.5~~2~~ provides similar results for the minimum flow mode. Since Technical Specifications require reactor depressurization when suppression pool temperature reaches 120 F, it is unlikely that a CS or RHR pump would be operating in a minimum flow mode for very long at that temperature. Table 2 shows adequate NPSH margin for pool temperatures ≥ 164 F. 8

~~Attachment 3 provides an assessment of the time-dependent NPSH margin for the maximum post-accident pool temperature transient. The purpose of this calculation was to show the margin available after the peak temperature is reached in light of the vendor recommended increase in minimum available NPSH after 7 hours. The minimum available NPSH is shown to be above the vendor recommended minimum at all times during the most limiting transient.~~ 8

Attachment 4 is an evaluation on the NPSH margin for the RHR pumps operating in the Shutdown Cooling mode. This evaluation is not directly related to the topic of post-LOCA ECCS performance, but the methods used are based on the methods in this calculation.

5.0 SUMMARY & CONCLUSIONS

SUMMARY

NPSHa is rounded to the nearest 0.1ft and OPR, OPC, and OPA are rounded to the nearest 0.1psig.

LOCA - Short Term (0-600 sec):
NPSHa is adequate for both CS and RHR pumps without crediting overpressure. NPSHa shown below is at the peak temperature.

Pump	Total flow, gpm	NPSHr, ft	NPSHa, ft
CS	4,600	28.0	28.4
1RHR	7,400	23.8	31.1
2 RHR	14,200	23.6	28.8

8

LOCA - Long Term (>600 sec):
NPSHa is adequate for both CS and RHR pumps with an overpressure credit that varies over time, as shown in Fig. 4.2. NPSHa, OPR, OPC, OPA are shown below, at the peak temperature

Pump	Total flow, gpm	NPSHr, ft	NPSHa, ft	OPR, psig	OPC, psig	OPA, psig
CS	3,500	29.6	19.5	4.2	6.1	7.8
1RHR	7,400	31.7	19.6	5.1	6.1	7.8

ATWS : 8

NPSHa is adequate for RHR with an overpressure required of 1.3 psig or less between 1000 and 5000 seconds, as shown in Fig. 4.3-1. The overpressure required is bounded by the overpressure credit requested for LOCA. 8

Pump	Total flow, gpm	NPSHr, ft	NPSHa, ft	OPR, psig	OPC, psig	OPA, psig
1RHR	7,400	23.8	20.8	1.3	2.4	12.3

The estimated effect of an increase in CST temperature is to increase the OPR by 0.1 psig. 8

General Profile – Overpressure Required vs. Pool Temperature

General profiles of "Overpressure Required vs. Pool Temperature", for the scenarios listed below are provided in Figures 4.4-1 through 4.4-4. The profiles are intended to serve as the basis for determining overpressure requirements when performing RHR and CS pump NPSH evaluation for any other events, which cause elevated suppression pool temperatures, without strainer debris loading. A representative flow range is presented based on available vendor data for NPSH. 8

Profiles

Figure	Pumps operating	Flow range, gpm	NPSHr
4.4-1	1 RHR	7000-7400	Minimum (0-7 hrs of operation)
4.4-1	1 RHR	7000-7400	Maximum (>7 hrs of operation)
4.4-2	2 RHR	12,800-14,200	Minimum (0-7 hrs of operation)
4.4-2	2 RHR	12,800-14,200	Maximum (>7 hrs of operation)
4.4-3	1 CS	3500-4600	Minimum (0-7 hrs of operation)
4.4-4	1 CS	3500-4600	Maximum (>7 hrs of operation)

8

Conclusions

There is adequate NPSH available for operating the RHR and CS pumps at EPU conditions for the DBA-Loss of Coolant Accident (LOCA), short term, without crediting torus overpressure.

Torus overpressure must be credited for operating the RHR and CS pumps at EPU conditions for the following events in order to achieve adequate NPSH available:

- DBA-Loss of Coolant Accident (LOCA), long term (200,000 seconds)
- Anticipated Transients Without Scram (ATWS) 8

The overpressure credit required for LOCA bounds that required for ATWS.

A basis for readily determining overpressure requirements, when performing RHR and CS pump NPSH evaluation for any other events which cause elevated suppression pool temperatures has provided in the form of a family of curves profiling overpressure required vs. pool temperature.

Note that use of overpressure credit must be approved by the NRC as part of EPU.

No specific 50.59 Screening/Evaluation is required since power uprate will require NRC approval.

~~Available NPSH exceeds required NPSH for the limiting conditions evaluated, short-term and long-term. This includes margin to accommodate the maximum head loss across the Core Spray and RHR suction strainers due to the predicted accumulation of fibrous and other debris following a LOCA.~~ 8

~~There is no need to do a Safety Evaluation since the results continue to show adequate NPSH margins for the Core Spray and RHR pumps.~~ 8

The completion of this calculation also satisfies the commitment made in Ref. 16 to revise the NPSH calculation using a corrected curve fit for required NPSH for the RHR pump.

Impact on Other Design Output Documents

The results of this calculation will provide input to the power uprate license amendment request. The need for crediting torus overpressure in the RHR and CS NPSH evaluation, shall also be addressed in the SADBD, UFSAR, and system DBDs for Containment (CPS), RHR, and CS. 8

~~Design Basis Documents: The Core Spray, RHR, and CPS DBDs refer to VYC-808. This revision has no impact on any DBD.~~

VYC-0019, Rev. 1: Refers to VYC-808 for the Core Spray suction strainer head loss of 0.42 ft at 4000 gpm. Revision 6 to VYC-808 reduced that value to 0.38 ft, but the impact on VYC-0019, Rev. 1, was minimal and no change was required. This revision to VYC-808 does not change that conclusion.

VYC-1628, Rev. 0: Refers to VYC-808 in regards to the fact that Vermont Yankee does not credit any wetwell pressure above atmospheric in the calculation of available NPSH. This revision to VYC-808 does not change that fact.

VYC-1670, Rev. 0: Refers to VYC-808 in support of use of 5 ft as a conservative value for RHR suction strainer head loss. This revision to VYC-808 does not change that conclusion.

VYC-1677, Rev. 0: Refers to VYC-808 for the debris distribution based on the short-term and long-term flow splits documented in Section 4.1.4. This revision does not change the flow splits.

VYC-1803, Rev. 1: Refers to VYC-808 as the basis for the calculation of available NPSH for RHR pumps at elevated suppression pool temperatures. This revision of VYC-808 does not change that statement.

VYPC 96-015, Rev. 2: Refers to VYC-808 as the basis for concluding that there is no need to throttle an RHR pump while operating in the torus cooling mode. This revision to VYC-808 does not change that conclusion.

Design basis documents will be updated upon NRC approval of the power uprate and as part of the power uprate implementation via VYDC 2003-008. 8

6.0 REFERENCES

1. American National Standard for Centrifugal Pumps, ANSI/HI 1.1-1.5-1994.

2. VYC-1924, Rev. 0, "DE&S Calc. DC-A34600.006, 'Vermont Yankee ECCS Suction Strainer Head Loss Performance Assessment, RHR and CS Debris Head Loss Calculations.'"

3. VYC-1677, "Debris Source Terms For Sizing of Replacement Residual Heat Removal and Core Spray Strainers."

4. Letter, USNRC to VYNPC, Vermont Yankee Design Inspection (NRC Inspection Report 50/271/97-201), NVY 97-130, dated August 27, 1997.

5. not used~~VYC-1628F, "Limiting Torus Temperature Response, Million Second Run."~~ 8

6. VYC-1919, Rev. 0, "DE&S Calc. DC-A34600-01, "RHR and CS Suction Strainer Assembly Clean Head Loss."

7. Memo, R.E.Swenson/P.A.Rainey to M.Mills, "Evaluation of Maximum Expected Flows for ECCS Strainer Replacement," VYS 98/97, dated August 28, 1997.

8. OP-2124, Rev. 52, "Residual Heat Removal System".

9. not used~~VYC-1924, Rev. 0, CCN02, "DE&S Calc. DC-A34600.006, 'Vermont Yankee ECCS Suction Strainer Head Loss Performance Assessment, RHR and CS Debris Head Loss Calculations.'"~~ 8

10. ~~not used~~Letter, GE-VYNPS-AEP-346, Rev. 2, dated August 7, 2004. 8

11. ~~not used~~GE Final Task Report, Task T0902, GE-NE-0000-0016-3831-01, Rev. 0, dated July 2003. 8

12. ~~not used~~ERC No. 2003-027 8

13. Drawing 6202-1, Rev. 1, "General Plan--Pressure Suppression Containment Vessel."

14. not used

15. not used

16. Letter, VYNPC to USNRC, "Reply to Inspection Report No. 50-271/97-201," (Appendix B, IFI 97-201-04), BVY 97-138, dated 10/27/97.

17. not used

18. not used

19. not used ~~DE&S Memo, C. D. Fago to J. R. Hoffman, "Torus Temperature Margin Assessment for Confirmatory Analyses," THSAG-VY-98-064, dated April 27, 1998.~~ 8

20. Memo, B. C. Slifer to K. H. Bronson, "NPSH Limits for Emergency Operating Procedures," VYS 98/58, dated May 13, 1998.

21. VYC-717B, Rev. 0, "Core Spray Pump Discharge Flow, Supplemental Addition to Revision 1."

22. not used ~~Letter, USNRC to VYNPC, "Summary of Meeting on March 24, 1998, regarding Activities at Vermont Yankee Nuclear Power Station (TAC No. MA0987)," NVY 98-43, dated March 31, 1998.~~ 8

23. not used ~~VYC-1628, Rev. 0, "Torus Temperature and Pressure Response to Large Break LOCA and MSLB Accident Scenarios."~~ 8

24. VYC-1254, Rev. 3, "Containment RPV Volume Calculations."

25. Drawing G-191207, Rev. 10

26. Drawing G-191211, Rev. 17

Table 4.1
LOCA - Short term (1.5 wt. % Containment Leakage 100% Spray Efficiency)

LOCA - Short Term

NPSHa = (14.7-Pg)(144Vf)+Z-hf-hs-hd
OPR = (NPSHr – NPSHa)/(144*Vf)
OPA = Over pressure available
OPC = Over pressure credited

Short Term Flow Rate (gpm)

1 RHR	Q = 7400	CS	Q = 4600
2 RHR	Q = 14200		

Suction Line Losses (ft)

1 RHR	hf = 4.77E-8*Q^2	CS	hf = 2.5E-7*Q^2
2 RHR	hf = 7.84E-8*(Q/2)^2		

Clean Strainer Losses (ft)

1 RHR	hs = 0.33	CS	hs = 0.51
2 RHR	hs = 1.22		

Maximum Debris Losses (ft) @ >=base temperature

1 RHR	hd = 0.33@173F	CS	hd = 0.32@173F
2 RHR	hd = 0.48@170F		

Maximum Debris Losses (ft) @ < base temperature

1 RHR	hd = .33*(173/T)	CS	hd = .32*(173/T)
2 RHR	hd = .48*(170/T)		

where T = suppression pool temperature, F

Elevation Head (ft)

RHR	Z = 12.3	CS	Z = 12.47

NPSHr (ft)

1 RHR	NPSHr = 23.8	CS	NPSHr = 28.0
2 RHR	NPSHr = 23.6		

Short Term (After EPU) - Peak Torus Temperature - 1.5 wt. % Containment Leakage & 100% Spray Efficiency

Pump(s)	Time (sec)	GE Pool Temp (F)	GE Pool Pressure psia	Pg (psia)	Vf (ft^3/lb)	Z (ft)	hf (ft)	hs (ft)	hd (ft)	NPSHa (ft)	NPSHr (ft)	OPR (psig)	OPA (psig)	OPC (psig)
CS	600	165.1	17.64	5.349	0.016423	12.47	5.29	0.51	0.34	28.44	28.00	0.00	2.94	0.00
1 RHR	600	165.1	17.64	5.349	0.016423	12.30	2.61	0.33	0.35	31.12	23.80	0.00	2.94	0.00
2 RHR	600	165.1	17.64	5.349	0.016423	12.30	3.95	1.22	0.49	28.75	23.60	0.00	2.94	0.00

Table 4.2
LOCA - Long term (1.5 wt. % Containment Leakage 100% Spray Efficiency)

LOCA - Long Term

NPSHa =	(14.7-Pg)(144Vf)+Z-hf-hs-hd
OPR =	Over pressure required (NPSHr – NPSHa)/(144*Vf)
OPA =	Over pressure available
OPC =	Over pressure credited

<u>Long Term Flow Rate (gpm)</u>

1 RHR	Q = 7400	CS	Q = 3500

<u>Suction Line Losses (ft)</u>

1 RHR	hf = 4.77E-8*Q^2	CS	hf = 2.5E-7*Q^2

<u>Clean Strainer Losses (ft)</u>

1 RHR	hs = 0.33	CS	hs = .38*(Q/4000)^2 for Q<= 4000

<u>Maximum Debris Losses (ft) @ >= 173F</u>

1 RHR	hd = 0.33	CS	hd = 0.21

<u>Maximum Debris Losses (ft) @ < 173F</u>

1 RHR	hd = .33*(173/T)	CS	hd = .21*(173/T)

where T = suppression pool temperature, F

<u>Elevation Head (ft)</u>

RHR	Z = 12.4	CS	Z = 12.57

<u>NPSHr (ft)</u>

1 RHR	NPSHr = 31.7	CS	NPSHr = 29.6

Table 4.2
LOCA - Long term (1.5 wt. % Containment Leakage 100% Spray Efficiency)

CS - Long Term (After EPU) 1.5 wt. % Containment Leakage & 100% Spray Efficiency

Time (sec)	GE Pool Temp (F)	GE Pool Pressure psia	Pg (psia)	Vf (ft^3/lb)	Z (ft)	hf (ft)	hs (ft)	hd (ft)	CS NPSHa (ft)	CS NPSHr (ft)	CS OPR (psig)	OPA (psig)	OPC (psig)
786	169.7	17.71	5.951	0.016449	12.57	3.06	0.29	0.21	29.73	29.60	0.00	3.01	2.40
1,098	171.8	17.94	6.245	0.016461	12.57	3.06	0.29	0.21	29.05	29.60	0.23	3.24	2.40
2,033	176.6	18.57	6.962	0.016489	12.57	3.06	0.29	0.21	27.38	29.60	0.94	3.87	3.40
2,962	180.0	19.17	7.511	0.016509	12.57	3.06	0.29	0.21	26.10	29.60	1.47	4.47	3.40
4,196	183.4	19.90	8.096	0.016530	12.57	3.06	0.29	0.21	24.73	29.60	2.05	5.20	4.40
5,125	185.2	20.34	8.420	0.016541	12.57	3.06	0.29	0.21	23.96	29.60	2.37	5.64	4.40
6,275	187.0	20.82	8.756	0.016552	12.57	3.06	0.29	0.21	23.17	29.60	2.70	6.12	5.10
8,036	189.1	21.50	9.161	0.016566	12.57	3.06	0.29	0.21	22.22	29.60	3.09	6.80	5.10
10,220	191.0	21.86	9.541	0.016578	12.57	3.06	0.29	0.21	21.32	29.60	3.47	7.16	6.10
12,094	192.2	22.06	9.788	0.016585	12.57	3.06	0.29	0.21	20.74	29.60	3.71	7.36	6.10
15,170	193.6	22.31	10.083	0.016594	12.57	3.06	0.29	0.21	20.04	29.60	4.00	7.61	6.10
17,669	194.3	22.43	10.233	0.016599	12.57	3.06	0.29	0.21	19.68	29.60	4.15	7.73	6.10
20,156	194.6	22.46	10.298	0.016601	12.57	3.06	0.29	0.21	19.53	29.60	4.21	7.76	6.10
23,812	194.7	22.48	10.320	0.016601	12.57	3.06	0.29	0.21	19.48	29.60	4.23	7.78	6.10
24,495	194.7	22.48	10.320	0.016601	12.57	3.06	0.29	0.21	19.48	29.60	4.23	7.78	6.10
25,120	194.7	22.47	10.320	0.016601	12.57	3.06	0.29	0.21	19.48	29.60	4.23	7.77	6.10
30,095	194.3	22.42	10.233	0.016599	12.57	3.06	0.29	0.21	19.68	29.60	4.15	7.72	6.10
35,065	193.7	22.33	10.104	0.016595	12.57	3.06	0.29	0.21	19.99	29.60	4.02	7.63	6.10
40,020	192.8	22.20	9.914	0.016589	12.57	3.06	0.29	0.21	20.44	29.60	3.83	7.50	5.60
45,637	191.5	22.01	9.644	0.016581	12.57	3.06	0.29	0.21	21.08	29.60	3.57	7.31	5.60
49,406	190.4	21.78	9.420	0.016574	12.57	3.06	0.29	0.21	21.61	29.60	3.35	7.08	5.60
60,551	187.2	21.21	8.794	0.016554	12.57	3.06	0.29	0.21	23.09	29.60	2.73	6.51	4.60
70,342	184.4	20.72	8.275	0.016536	12.57	3.06	0.29	0.21	24.31	29.60	2.22	6.02	4.10
80,342	181.8	20.28	7.816	0.016520	12.57	3.06	0.29	0.21	25.38	29.60	1.77	5.58	3.60
90,340	179.3	19.89	7.395	0.016505	12.57	3.06	0.29	0.21	26.37	29.60	1.36	5.19	3.10
100,340	176.8	19.52	6.994	0.016490	12.57	3.06	0.29	0.21	27.30	29.60	0.97	4.82	3.10
110,340	174.8	19.20	6.686	0.016478	12.57	3.06	0.29	0.21	28.02	29.60	0.66	4.50	2.60
120,306	173.2	18.93	6.447	0.016469	12.57	3.06	0.29	0.21	28.58	29.60	0.43	4.23	2.60
130,302	171.8	18.69	6.245	0.016461	12.57	3.06	0.29	0.21	29.05	29.60	0.23	3.99	2.10
140,302	170.4	18.47	6.048	0.016453	12.57	3.06	0.29	0.21	29.51	29.60	0.04	3.77	2.10
150,302	169.1	18.27	5.870	0.016445	12.57	3.06	0.29	0.21	29.92	29.60	0.00	3.57	1.70
160,302	167.8	18.07	5.696	0.016438	12.57	3.06	0.29	0.22	30.31	29.60	0.00	3.37	1.70
170,302	166.6	17.90	5.539	0.016431	12.57	3.06	0.29	0.22	30.67	29.60	0.00	3.20	1.30
180,302	165.3	17.72	5.374	0.016424	12.57	3.06	0.29	0.22	31.05	29.60	0.00	3.02	1.30
190,302	164.1	17.54	5.225	0.016417	12.57	3.06	0.29	0.22	31.40	29.60	0.00	2.84	1.30
194,052	163.6	17.47	5.164	0.016414	12.57	3.06	0.29	0.22	31.54	29.60	0.00	2.77	1.30
196,552	163.3	17.43	5.127	0.016413	12.57	3.06	0.29	0.22	31.62	29.60	0.00	2.73	1.30
197,802	163.2	17.41	5.115	0.016412	12.57	3.06	0.29	0.22	31.65	29.60	0.00	2.71	1.30
200,302	162.9	17.37	5.079	0.016411	12.57	3.06	0.29	0.22	31.73	29.60	0.00	2.67	0.00

Table 4.2
LOCA - Long term (1.5 wt. % Containment Leakage 100% Spray Efficiency)

RHR - Long Term (After EPU) 1.5 wt. % Containment Leakage & 100% Spray Efficiency

Time (sec)	GE Pool Temp (F)	GE Pool Pressure psia	Pg (psia)	Vf (ft^3/lb)	Z (ft)	hf (ft)	hs (ft)	hd (ft)	RHR NPSHa (ft)	RHR NPSHr (ft)	RHR OPR (psig)	OPA (psig)	OPC (psig)
786	169.7	17.71	5.951	0.016449	12.40	2.61	0.33	0.34	29.84	31.70	0.78	3.01	2.40
1,098	171.8	17.94	6.245	0.016461	12.40	2.61	0.33	0.33	29.17	31.70	1.07	3.24	2.40
2,033	176.6	18.57	6.962	0.016489	12.40	2.61	0.33	0.33	27.50	31.70	1.77	3.87	3.40
2,962	180.0	19.17	7.511	0.016509	12.40	2.61	0.33	0.33	26.22	31.70	2.31	4.47	3.40
4,196	183.4	19.90	8.096	0.016530	12.40	2.61	0.33	0.33	24.85	31.70	2.88	5.20	4.40
5,125	185.2	20.34	8.420	0.016541	12.40	2.61	0.33	0.33	24.09	31.70	3.20	5.64	4.40
6,275	187.0	20.82	8.756	0.016552	12.40	2.61	0.33	0.33	23.30	31.70	3.53	6.12	5.10
8,036	189.1	21.50	9.161	0.016566	12.40	2.61	0.33	0.33	22.34	31.70	3.92	6.80	5.10
10,220	191.0	21.86	9.541	0.016578	12.40	2.61	0.33	0.33	21.44	31.70	4.30	7.16	6.10
12,094	192.2	22.06	9.788	0.016585	12.40	2.61	0.33	0.33	20.86	31.70	4.54	7.36	6.10
15,170	193.6	22.31	10.083	0.016594	12.40	2.61	0.33	0.33	20.16	31.70	4.83	7.61	6.10
17,669	194.3	22.43	10.233	0.016599	12.40	2.61	0.33	0.33	19.81	31.70	4.98	7.73	6.10
20,156	194.6	22.46	10.298	0.016601	12.40	2.61	0.33	0.33	19.65	31.70	5.04	7.76	6.10
23,812	194.7	22.48	10.320	0.016601	12.40	2.61	0.33	0.33	19.60	31.70	5.06	7.78	6.10
24,495	194.7	22.48	10.320	0.016601	12.40	2.61	0.33	0.33	19.60	31.70	5.06	7.78	6.10
25,120	194.7	22.47	10.320	0.016601	12.40	2.61	0.33	0.33	19.60	31.70	5.06	7.77	6.10
30,095	194.3	22.42	10.233	0.016599	12.40	2.61	0.33	0.33	19.81	31.70	4.98	7.72	6.10
35,065	193.7	22.33	10.104	0.016595	12.40	2.61	0.33	0.33	20.11	31.70	4.85	7.63	6.10
40,020	192.8	22.20	9.914	0.016589	12.40	2.61	0.33	0.33	20.56	31.70	4.66	7.50	5.60
45,637	191.5	22.01	9.644	0.016581	12.40	2.61	0.33	0.33	21.20	31.70	4.40	7.31	5.60
49,406	190.4	21.78	9.420	0.016574	12.40	2.61	0.33	0.33	21.73	31.70	4.18	7.08	5.60
60,551	187.2	21.21	8.794	0.016554	12.40	2.61	0.33	0.33	23.21	31.70	3.56	6.51	4.60
70,342	184.4	20.72	8.275	0.016536	12.40	2.61	0.33	0.33	24.43	31.70	3.05	6.02	4.10
80,342	181.8	20.28	7.816	0.016520	12.40	2.61	0.33	0.33	25.50	31.70	2.60	5.58	3.60
90,340	179.3	19.89	7.395	0.016505	12.40	2.61	0.33	0.33	26.49	31.70	2.19	5.19	3.10
100,340	176.8	19.52	6.994	0.016490	12.40	2.61	0.33	0.33	27.43	31.70	1.80	4.82	3.10
110,340	174.8	19.20	6.686	0.016478	12.40	2.61	0.33	0.33	28.14	31.70	1.50	4.50	2.60
120,306	173.2	18.93	6.447	0.016469	12.40	2.61	0.33	0.33	28.70	31.70	1.26	4.23	2.60
130,302	171.8	18.69	6.245	0.016461	12.40	2.61	0.33	0.33	29.17	31.70	1.07	3.99	2.10
140,302	170.4	18.47	6.048	0.016453	12.40	2.61	0.33	0.34	29.62	31.70	0.88	3.77	2.10
150,302	169.1	18.27	5.870	0.016445	12.40	2.61	0.33	0.34	30.03	31.70	0.71	3.57	1.70
160,302	167.8	18.07	5.696	0.016438	12.40	2.61	0.33	0.34	30.43	31.70	0.54	3.37	1.70
170,302	166.6	17.90	5.539	0.016431	12.40	2.61	0.33	0.34	30.79	31.70	0.38	3.20	1.30
180,302	165.3	17.72	5.374	0.016424	12.40	2.61	0.33	0.35	31.16	31.70	0.23	3.02	1.30
190,302	164.1	17.54	5.225	0.016417	12.40	2.61	0.33	0.35	31.51	31.70	0.08	2.84	1.30
194,052	163.6	17.47	5.164	0.016414	12.40	2.61	0.33	0.35	31.65	31.70	0.02	2.77	1.30
196,552	163.3	17.43	5.127	0.016413	12.40	2.61	0.33	0.35	31.73	31.70	0.00	2.73	1.30
197,802	163.2	17.41	5.115	0.016412	12.40	2.61	0.33	0.35	31.76	31.70	0.00	2.71	1.30
200,302	162.9	17.37	5.079	0.016411	12.40	2.61	0.33	0.35	31.84	31.70	0.00	2.67	0.00

Table 4.3
ATWS

ATWS

NPSHa =	(14.7-Pg)(144Vf)+Z-hf-hs-hd
OPR =	(NPSHr – NPSHa)/(144*Vf)
OPA =	Over pressure available
OPC =	Over pressure credited
NPSHcm =	NPSH credited margin (NPSHa+OPC(144*vf) -NPSHr)

Flow Rate (gpm)
1 RHR Q = 7400

Suction Line Losses (ft)
1 RHR hf = 4.77E-8*Q^2

Clean Strainer Losses (ft)
1 RHR hs = 0.33

Maximum Debris Losses (ft)
1 RHR hd = 0.33

Elevation Head (ft)
RHR Z = 11.25

NPSHr (ft) 0-7 hrs
1 RHR NPSHr = 23.8

Table 4.3
ATWS

Minimum NPSHr (0-7 hrs of operation)

Pump(s)	Time (sec)	GE Pool Temp (F)	GE Pool Pressure psia	Pg (psia)	Vf (ft^3/lb)	Z (ft)	hf (ft)	hs (ft)	hd (ft)	NPSHa (ft)	NPSHr (ft)	OPR (psig)	OPA (psig)
1 RHR	300	160.0	21.00	4.741	0.016394	11.25	2.61	0.33	0.33	31.49	23.80	-3.26	6.30
1 RHR	600	175.0	22.90	6.716	0.016479	11.25	2.61	0.33	0.33	26.92	23.80	-1.32	8.20
1 RHR	1,000	182.0	25.40	7.850	0.016521	11.25	2.61	0.33	0.33	24.27	23.80	-0.20	10.70
1 RHR	1,300	187.0	26.20	8.756	0.016552	11.25	2.61	0.33	0.33	22.15	23.80	0.69	11.50
1 RHR	1,838	190.0	27.00	9.340	0.016571	11.25	2.61	0.33	0.33	20.77	23.80	1.27	12.30
1 RHR	3,000	187.0	26.60	8.756	0.016552	11.25	2.61	0.33	0.33	22.15	23.80	0.69	11.90
1 RHR	5,000	182.0	25.90	7.850	0.016521	11.25	2.61	0.33	0.33	24.27	23.80	-0.20	11.20
1 RHR	6,000	180.0	25:50	7.511	0.016509	11.25	2.61	0.33	0.33	25.07	23.80	-0.53	10.80
1 RHR	8,000	175.0	24.70	6.716	0.016479	11.25	2.61	0.33	0.33	26.92	23.80	-1.32	10.00

Sensitivity to Peak Pool Temperature

Pump(s)	Time (sec)	GE Pool Temp (F)	GE Pool Pressure psia	Pg (psia)	Vf (ft^3/lb)	Z (ft)	hf (ft)	hs (ft)	hd (ft)	NPSHa (ft)	NPSHr (ft)	OPR (psig)	OPA (psig)
1 RHR	N/A	190.0	27.00	9.340	0.016571	11.25	2.61	0.33	0.33	20.77	23.80	1.27	12.30
		190.5	27.20	9.440	0.016574	11.25	2.61	0.33	0.33	20.53	23.80	1.37	12.50

Table 4.4
General Profile - Overpressure vs Pool Temperature

General Profile – Overpressure Required vs Pool Temperature

NPSHa = (14.7-Pg)(144Vf)+Z-hf-hs-hd
OPR = (NPSHr – NPSHa)/(144*Vf)

<u>Flow Rate (gpm)</u>

	1 RHR	2 RHR	CS
high Q	7400	14200	4600
low Q	7000	12800	3500

<u>Suction Line Losses (ft)</u>

	1 RHR	2 RHR	CS
hf =	4.77E-8*Q^2	7.84E-8*(Q/2)^2	2.5E-7*Q^2

<u>Clean Strainer Losses (ft) @ flow rates tabulated above</u>

	1 RHR	2 RHR	CS
(high Q) hs	0.33	1.22	0.51
(low Q) hs	.33*(Q/7400)^2	1.22*(Q/14200)^2	.38*(Q/4000)^2

<u>Maximum Debris Losses (ft)</u>

	1 RHR	2 RHR	CS
hd	0	0	0

<u>Elevation Head (ft)</u>

	RHR	CS
Z	11.25	11.42

<u>Minimum NPSHr (ft) @ flow rates tabulated above</u>

	1 RHR	2 RHR	CS
(High Q) NPSHr	23.8	23.6	28.0
(Low Q) NPSHr	23.5	23.0	24.8

<u>Maximum NPSHr (ft) @ flow rates tabulated above</u>

	1 RHR	2 RHR	CS
(High Q) NPSHr	31.7	30.0	35.0
(Low Q) NPSHr	29.5	28.5	29.6

Table 4.4
General Profile - Overpressure vs Pool Temperature

General Profile – Overpressure Required vs Pool Temperature **1 RHR @ Min NPSHr** **(0-7 hrs of operation)**

Pump(s)	Flow, Q (gpm)	Pool Temp (F)	Pool Pressure psia	Pg (psia)	Vf (ft^3/lb)	Z (ft)	hf (ft)	hs (ft)	hd (ft)	NPSHa (ft)	NPSHr (ft)	OPR (psig)
1RHR	7,400	175.0	14.70	6.716	0.016480	11.25	2.61	0.33	0.00	27.25	23.80	-1.46
1RHR	7,400	180.0	14.70	7.511	0.016510	11.25	2.61	0.33	0.00	25.40	23.80	-0.67
1RHR	7,400	185.0	14.70	8.384	0.016540	11.25	2.61	0.33	0.00	23.35	23.80	0.19
1RHR	7,400	190.0	14.70	9.340	0.016572	11.25	2.61	0.33	0.00	21.10	23.80	1.13
1RHR	7,400	195.0	14.70	10.385	0.016604	11.25	2.61	0.33	0.00	18.63	23.80	2.16
1RHR	7,400	200.0	14.70	11.526	0.016637	11.25	2.61	0.33	0.00	15.91	23.80	3.29
1RHR	7,400	205.0	14.70	12.770	0.016670	11.25	2.61	0.33	0.00	12.94	23.80	4.52
1RHR	7,000	175.0	14.70	6.716	0.016480	11.25	2.34	0.30	0.00	27.56	23.50	-1.71
1RHR	7,000	180.0	14.70	7.511	0.016510	11.25	2.34	0.30	0.00	25.70	23.50	-0.93
1RHR	7,000	185.0	14.70	8.384	0.016540	11.25	2.34	0.30	0.00	23.66	23.50	-0.07
1RHR	7,000	190.0	14.70	9.340	0.016572	11.25	2.34	0.30	0.00	21.40	23.50	0.88
1RHR	7,000	195.0	14.70	10.385	0.016604	11.25	2.34	0.30	0.00	18.93	23.50	1.91
1RHR	7,000	200.0	14.70	11.526	0.016637	11.25	2.34	0.30	0.00	16.22	23.50	3.04
1RHR	7,000	205.0	14.70	12.770	0.016670	11.25	2.34	0.30	0.00	13.25	23.50	4.27

Table 4.4
General Profile - Overpressure vs Pool Temperature

General Profile – Overpressure Required vs Pool Temperature **2 RHR @ Min NPSHr** **(0-7 hrs of operation)**

Pump(s)	Flow, Q (gpm)	Pool Temp (F)	Pool Pressure psia	Pg (psia)	Vf (ft^3/lb)	Z (ft)	hf (ft)	hs (ft)	hd (ft)	NPSHa (ft)	NPSHr (ft)	OPR (psig)
2RHR	14,200	170.0	14.70	5.993	0.016451	11.25	3.95	1.22	0.00	26.70	23.60	-1.31
2RHR	14,200	175.0	14.70	6.716	0.016480	11.25	3.95	1.22	0.00	25.02	23.60	-0.60
2RHR	14,200	180.0	14.70	7.511	0.016510	11.25	3.95	1.22	0.00	23.17	23.60	0.18
2RHR	14,200	185.0	14.70	8.384	0.016540	11.25	3.95	1.22	0.00	21.12	23.60	1.04
2RHR	14,200	190.0	14.70	9.340	0.016572	11.25	3.95	1.22	0.00	18.87	23.60	1.98
2RHR	14,200	195.0	14.70	10.385	0.016604	11.25	3.95	1.22	0.00	16.39	23.60	3.01
2RHR	14,200	200.0	14.70	11.526	0.016637	11.25	3.95	1.22	0.00	13.68	23.60	4.14
2RHR	14,200	205.0	14.70	12.770	0.016670	11.25	3.95	1.22	0.00	10.71	23.60	5.37
2RHR	12,800	170.0	14.70	5.993	0.016451	11.25	3.21	0.99	0.00	27.68	23.00	-1.97
2RHR	12,800	175.0	14.70	6.716	0.016480	11.25	3.21	0.99	0.00	26.00	23.00	-1.26
2RHR	12,800	180.0	14.70	7.511	0.016510	11.25	3.21	0.99	0.00	24.14	23.00	-0.48
2RHR	12,800	185.0	14.70	8.384	0.016540	11.25	3.21	0.99	0.00	22.09	23.00	0.38
2RHR	12,800	190.0	14.70	9.340	0.016572	11.25	3.21	0.99	0.00	19.84	23.00	1.32
2RHR	12,800	195.0	14.70	10.385	0.016604	11.25	3.21	0.99	0.00	17.37	23.00	2.36
2RHR	12,800	200.0	14.70	11.526	0.016637	11.25	3.21	0.99	0.00	14.65	23.00	3.48
2RHR	12,800	205.0	14.70	12.770	0.016670	11.25	3.21	0.99	0.00	11.68	23.00	4.72

Table 4.4
General Profile - Overpressure vs Pool Temperature

General Profile – Overpressure Required vs Pool Temperature **CS Min NPSHr** **(0-7 hrs of operation)**

Pump(s)	Flow, Q (gpm)	Pool Temp (F)	Pool Pressure psia	Pg (psia)	Vf (ft^3/lb)	Z (ft)	hf (ft)	hs (ft)	hd (ft)	NPSHa (ft)	NPSHr (ft)	OPR (psig)
CS	4,600	155.0	14.70	4.204	0.016368	11.42	5.29	0.51	0.00	30.36	28.00	-1.00
CS	4,600	160.0	14.70	4.741	0.016395	11.42	5.29	0.51	0.00	29.13	28.00	-0.48
CS	4,600	165.0	14.70	5.336	0.016422	11.42	5.29	0.51	0.00	27.76	28.00	0.10
CS	4,600	170.0	14.70	5.993	0.016451	11.42	5.29	0.51	0.00	26.25	28.00	0.74
CS	4,600	175.0	14.70	6.716	0.016480	11.42	5.29	0.51	0.00	24.57	28.00	1.45
CS	4,600	180.0	14.70	7.511	0.016510	11.42	5.29	0.51	0.00	22.71	28.00	2.22
CS	4,600	185.0	14.70	8.384	0.016540	11.42	5.29	0.51	0.00	20.66	28.00	3.08
CS	4,600	190.0	14.70	9.340	0.016572	11.42	5.29	0.51	0.00	18.41	28.00	4.02
CS	4,600	195.0	14.70	10.385	0.016604	11.42	5.29	0.51	0.00	15.94	28.00	5.05
CS	4,600	200.0	14.70	11.526	0.016637	11.42	5.29	0.51	0.00	13.22	28.00	6.17
CS	4,600	205.0	14.70	12.770	0.016670	11.42	5.29	0.51	0.00	10.25	28.00	7.39
CS	3,500	155.0	14.70	4.204	0.016368	11.42	3.06	0.29	0.00	32.81	24.80	-3.40
CS	3,500	160.0	14.70	4.741	0.016395	11.42	3.06	0.29	0.00	31.58	24.80	-2.87
CS	3,500	165.0	14.70	5.336	0.016422	11.42	3.06	0.29	0.00	30.21	24.80	-2.29
CS	3,500	170.0	14.70	5.993	0.016451	11.42	3.06	0.29	0.00	28.69	24.80	-1.64
CS	3,500	175.0	14.70	6.716	0.016480	11.42	3.06	0.29	0.00	27.01	24.80	-0.93
CS	3,500	180.0	14.70	7.511	0.016510	11.42	3.06	0.29	0.00	25.16	24.80	-0.15
CS	3,500	185.0	14.70	8.384	0.016540	11.42	3.06	0.29	0.00	23.11	24.80	0.71
CS	3,500	190.0	14.70	9.340	0.016572	11.42	3.06	0.29	0.00	20.86	24.80	1.65
CS	3,500	195.0	14.70	10.385	0.016604	11.42	3.06	0.29	0.00	18.38	24.80	2.68
CS	3,500	200.0	14.70	11.526	0.016637	11.42	3.06	0.29	0.00	15.67	24.80	3.81
CS	3,500	205.0	14.70	12.770	0.016670	11.42	3.06	0.29	0.00	12.70	24.80	5.04

Table 4.4
General Profile - Overpressure vs Pool Temperature

General Profile – Overpressure Required vs Pool Temperature **1 RHR @ Max NPSHr** (>7 hrs of operation)

Pump(s)	Flow, Q (gpm)	Pool Temp (F)	Pool Pressure psia	Pg (psia)	Vf (ft^3/lb)	Z (ft)	hf (ft)	hs (ft)	hd (ft)	NPSHa (ft)	NPSHr (ft)	OPR (psig)
1RHR	7,400	155.0	14.70	4.204	0.016368	11.25	2.61	0.33	0.00	33.05	31.70	-0.57
1RHR	7,400	160.0	14.70	4.741	0.016395	11.25	2.61	0.33	0.00	31.82	31.70	-0.05
1RHR	7,400	165.0	14.70	5.336	0.016422	11.25	2.61	0.33	0.00	30.45	31.70	0.53
1RHR	7,400	170.0	14.70	5.993	0.016451	11.25	2.61	0.33	0.00	28.93	31.70	1.17
1RHR	7,400	175.0	14.70	6.716	0.016480	11.25	2.61	0.33	0.00	27.25	31.70	1.87
1RHR	7,400	180.0	14.70	7.511	0.016510	11.25	2.61	0.33	0.00	25.40	31.70	2.65
1RHR	7,400	185.0	14.70	8.384	0.016540	11.25	2.61	0.33	0.00	23.35	31.70	3.51
1RHR	7,400	190.0	14.70	9.340	0.016572	11.25	2.61	0.33	0.00	21.10	31.70	4.44
1RHR	7,400	195.0	14.70	10.385	0.016604	11.25	2.61	0.33	0.00	18.63	31.70	5.47
1RHR	7,400	200.0	14.70	11.526	0.016637	11.25	2.61	0.33	0.00	15.91	31.70	6.59
1RHR	7,400	205.0	14.70	12.770	0.016670	11.25	2.61	0.33	0.00	12.94	31.70	7.81
1RHR	7,000	155.0	14.70	4.204	0.016368	11.25	2.34	0.30	0.00	33.35	29.50	-1.63
1RHR	7,000	160.0	14.70	4.741	0.016395	11.25	2.34	0.30	0.00	32.12	29.50	-1.11
1RHR	7,000	165.0	14.70	5.336	0.016422	11.25	2.34	0.30	0.00	30.76	29.50	-0.53
1RHR	7,000	170.0	14.70	5.993	0.016451	11.25	2.34	0.30	0.00	29.24	29.50	0.11
1RHR	7,000	175.0	14.70	6.716	0.016480	11.25	2.34	0.30	0.00	27.56	29.50	0.82
1RHR	7,000	180.0	14.70	7.511	0.016510	11.25	2.34	0.30	0.00	25.70	29.50	1.60
1RHR	7,000	185.0	14.70	8.384	0.016540	11.25	2.34	0.30	0.00	23.66	29.50	2.45
1RHR	7,000	190.0	14.70	9.340	0.016572	11.25	2.34	0.30	0.00	21.40	29.50	3.39
1RHR	7,000	195.0	14.70	10.385	0.016604	11.25	2.34	0.30	0.00	18.93	29.50	4.42
1RHR	7,000	200.0	14.70	11.526	0.016637	11.25	2.34	0.30	0.00	16.22	29.50	5.54
1RHR	7,000	205.0	14.70	12.770	0.016670	11.25	2.34	0.30	0.00	13.25	29.50	6.77

Table 4.4
General Profile - Overpressure vs Pool Temperature

General Profile – Overpressure Required vs Pool Temperature **2 RHR @ Max NPSHr** (>7 hrs of operation)

Pump(s)	Flow, Q (gpm)	Pool Temp (F)	Pool Pressure psia	Pg (psia)	Vf (ft^3/lb)	Z (ft)	hf (ft)	hs (ft)	hd (ft)	NPSHa (ft)	NPSHr (ft)	OPR (psig)
2RHR	14,200	155.0	14.70	4.204	0.016368	11.25	3.95	1.22	0.00	30.82	30.00	-0.35
2RHR	14,200	160.0	14.70	4.741	0.016395	11.25	3.95	1.22	0.00	29.59	30.00	0.17
2RHR	14,200	165.0	14.70	5.336	0.016422	11.25	3.95	1.22	0.00	28.22	30.00	0.75
2RHR	14,200	170.0	14.70	5.993	0.016451	11.25	3.95	1.22	0.00	26.70	30.00	1.39
2RHR	14,200	175.0	14.70	6.716	0.016480	11.25	3.95	1.22	0.00	25.02	30.00	2.10
2RHR	14,200	180.0	14.70	7.511	0.016510	11.25	3.95	1.22	0.00	23.17	30.00	2.87
2RHR	14,200	185.0	14.70	8.384	0.016540	11.25	3.95	1.22	0.00	21.12	30.00	3.73
2RHR	14,200	190.0	14.70	9.340	0.016572	11.25	3.95	1.22	0.00	18.87	30.00	4.66
2RHR	14,200	195.0	14.70	10.385	0.016604	11.25	3.95	1.22	0.00	16.39	30.00	5.69
2RHR	14,200	200.0	14.70	11.526	0.016637	11.25	3.95	1.22	0.00	13.68	30.00	6.81
2RHR	14,200	205.0	14.70	12.770	0.016670	11.25	3.95	1.22	0.00	10.71	30.00	8.04
2RHR	12,800	155.0	14.70	4.204	0.016368	11.25	3.21	0.99	0.00	31.79	28.50	-1.39
2RHR	12,800	160.0	14.70	4.741	0.016395	11.25	3.21	0.99	0.00	30.56	28.50	-0.87
2RHR	12,800	165.0	14.70	5.336	0.016422	11.25	3.21	0.99	0.00	29.19	28.50	-0.29
2RHR	12,800	170.0	14.70	5.993	0.016451	11.25	3.21	0.99	0.00	27.68	28.50	0.35
2RHR	12,800	175.0	14.70	6.716	0.016480	11.25	3.21	0.99	0.00	26.00	28.50	1.06
2RHR	12,800	180.0	14.70	7.511	0.016510	11.25	3.21	0.99	0.00	24.14	28.50	1.83
2RHR	12,800	185.0	14.70	8.384	0.016540	11.25	3.21	0.99	0.00	22.09	28.50	2.69
2RHR	12,800	190.0	14.70	9.340	0.016572	11.25	3.21	0.99	0.00	19.84	28.50	3.63
2RHR	12,800	195.0	14.70	10.385	0.016604	11.25	3.21	0.99	0.00	17.37	28.50	4.66
2RHR	12,800	200.0	14.70	11.526	0.016637	11.25	3.21	0.99	0.00	14.65	28.50	5.78
2RHR	12,800	205.0	14.70	12.770	0.016670	11.25	3.21	0.99	0.00	11.68	28.50	7.01

Table 4.4
General Profile - Overpressure vs Pool Temperature

General Profile – Overpressure Required vs Pool Temperature **CS Max NPSHr** **(>7 hrs of operation)**

Pump(s)	Flow, Q (gpm)	Pool Temp (F)	Pool Pressure psia	Pg (psia)	Vf (ft^3/lb)	Z (ft)	hf (ft)	hs (ft)	hd (ft)	NPSHa (ft)	NPSHr (ft)	OPR (psig)
CS	4,600	125.0	14.70	1.942	0.016225	11.42	5.29	0.51	0.00	35.43	35.00	-0.18
CS	4,600	130.0	14.70	2.223	0.016246	11.42	5.29	0.51	0.00	34.81	35.00	0.08
CS	4,600	135.0	14.70	2.537	0.016269	11.42	5.29	0.51	0.00	34.11	35.00	0.38
CS	4,600	140.0	14.70	2.889	0.016293	11.42	5.29	0.51	0.00	33.33	35.00	0.71
CS	4,600	145.0	14.70	3.282	0.016317	11.42	5.29	0.51	0.00	32.45	35.00	1.09
CS	4,600	150.0	14.70	3.718	0.016342	11.42	5.29	0.51	0.00	31.46	35.00	1.50
CS	4,600	155.0	14.70	4.204	0.016368	11.42	5.29	0.51	0.00	30.36	35.00	1.97
CS	4,600	160.0	14.70	4.741	0.016395	11.42	5.29	0.51	0.00	29.13	35.00	2.49
CS	4,600	165.0	14.70	5.336	0.016422	11.42	5.29	0.51	0.00	27.76	35.00	3.06
CS	4,600	170.0	14.70	5.993	0.016451	11.42	5.29	0.51	0.00	26.25	35.00	3.70
CS	4,600	175.0	14.70	6.716	0.016480	11.42	5.29	0.51	0.00	24.57	35.00	4.40
CS	4,600	180.0	14.70	7.511	0.016510	11.42	5.29	0.51	0.00	22.71	35.00	5.17
CS	4,600	185.0	14.70	8.384	0.016540	11.42	5.29	0.51	0.00	20.66	35.00	6.02
CS	4,600	190.0	14.70	9.340	0.016572	11.42	5.29	0.51	0.00	18.41	35.00	6.95
CS	4,600	195.0	14.70	10.385	0.016604	11.42	5.29	0.51	0.00	15.94	35.00	7.97
CS	4,600	200.0	14.70	11.526	0.016637	11.42	5.29	0.51	0.00	13.22	35.00	9.09
CS	4,600	205.0	14.70	12.770	0.016670	11.42	5.29	0.51	0.00	10.25	35.00	10.31

Table 4.4
General Profile - Overpressure vs Pool Temperature

General Profile – Overpressure Required vs Pool Temperature **CS Max NPSHr** **(>7 hrs of operation)**

Pump(s)	Flow, Q (gpm)	Pool Temp (F)	Pool Pressure psia	Pg (psia)	Vf (ft^3/lb)	Z (ft)	hf (ft)	hs (ft)	hd (ft)	NPSHa (ft)	NPSHr (ft)	OPR (psig)
CS	3,500	125.0	14.70	1.942	0.016225	11.42	3.06	0.29	0.00	37.88	29.60	-3.54
CS	3,500	130.0	14.70	2.223	0.016246	11.42	3.06	0.29	0.00	37.26	29.60	-3.27
CS	3,500	135.0	14.70	2.537	0.016269	11.42	3.06	0.29	0.00	36.56	29.60	-2.97
CS	3,500	140.0	14.70	2.889	0.016293	11.42	3.06	0.29	0.00	35.78	29.60	-2.63
CS	3,500	145.0	14.70	3.282	0.016317	11.42	3.06	0.29	0.00	34.90	29.60	-2.25
CS	3,500	150.0	14.70	3.718	0.016342	11.42	3.06	0.29	0.00	33.91	29.60	-1.83
CS	3,500	155.0	14.70	4.204	0.016368	11.42	3.06	0.29	0.00	32.81	29.60	-1.36
CS	3,500	160.0	14.70	4.741	0.016395	11.42	3.06	0.29	0.00	31.58	29.60	-0.84
CS	3,500	165.0	14.70	5.336	0.016422	11.42	3.06	0.29	0.00	30.21	29.60	-0.26
CS	3,500	170.0	14.70	5.993	0.016451	11.42	3.06	0.29	0.00	28.69	29.60	0.38
CS	3,500	175.0	14.70	6.716	0.016480	11.42	3.06	0.29	0.00	27.01	29.60	1.09
CS	3,500	180.0	14.70	7.511	0.016510	11.42	3.06	0.29	0.00	25.16	29.60	1.87
CS	3,500	185.0	14.70	8.384	0.016540	11.42	3.06	0.29	0.00	23.11	29.60	2.72
CS	3,500	190.0	14.70	9.340	0.016572	11.42	3.06	0.29	0.00	20.86	29.60	3.66
CS	3,500	195.0	14.70	10.385	0.016604	11.42	3.06	0.29	0.00	18.38	29.60	4.69
CS	3,500	200.0	14.70	11.526	0.016637	11.42	3.06	0.29	0.00	15.67	29.60	5.81
CS	3,500	205.0	14.70	12.770	0.016670	11.42	3.06	0.29	0.00	12.70	29.60	7.04

TABLE 4.5

VYC-808, Revision 8

NPSHA = (14.7 - P_g)(144)(v_f) + Z - h_f - h_s - h_d

<u>Suction Line Losses</u>

1 RHR	h_f = 4.77e-8*Q^2	CS	h_f = 2.5e-7*Q^2
2 RHR	h_f = 7.84e-8*(Q/2)^2		

<u>Clean Strainer Losses</u>

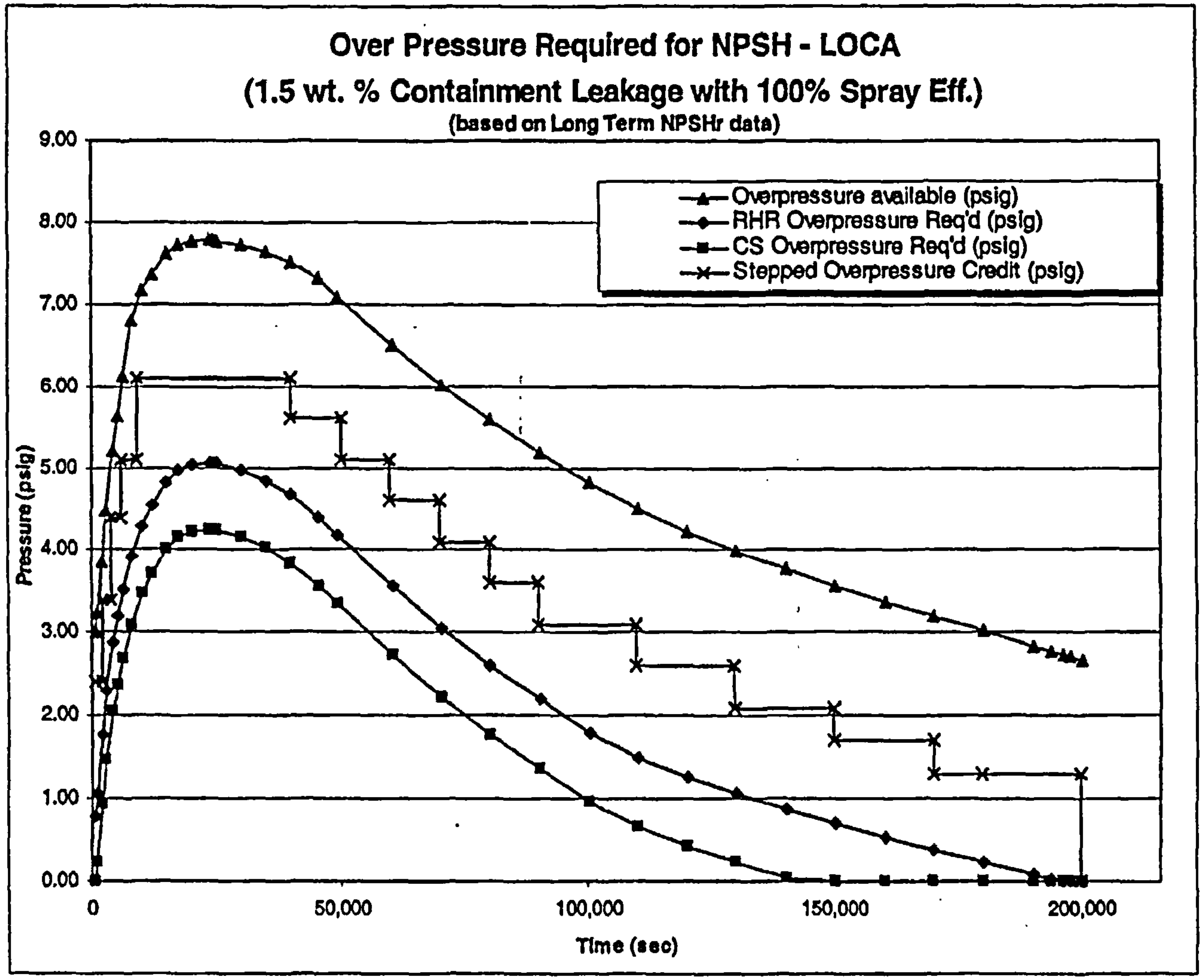
1 RHR	h_s = 0.33*(Q/7400)^2	CS	h_s = 0.38*(Q/4000)^2
2 RHR	h_s = 1.22*(Q/14200)^2		

<u>Required NPSH</u>

RHR	NPSHR =	30	@ 350 gpm	CS	NPSHR =	32.5	@ 300 gpm
RHR	NPSHR =	26	@ 2700 gpm	CS	NPSHR =	27	@ 1250 gpm

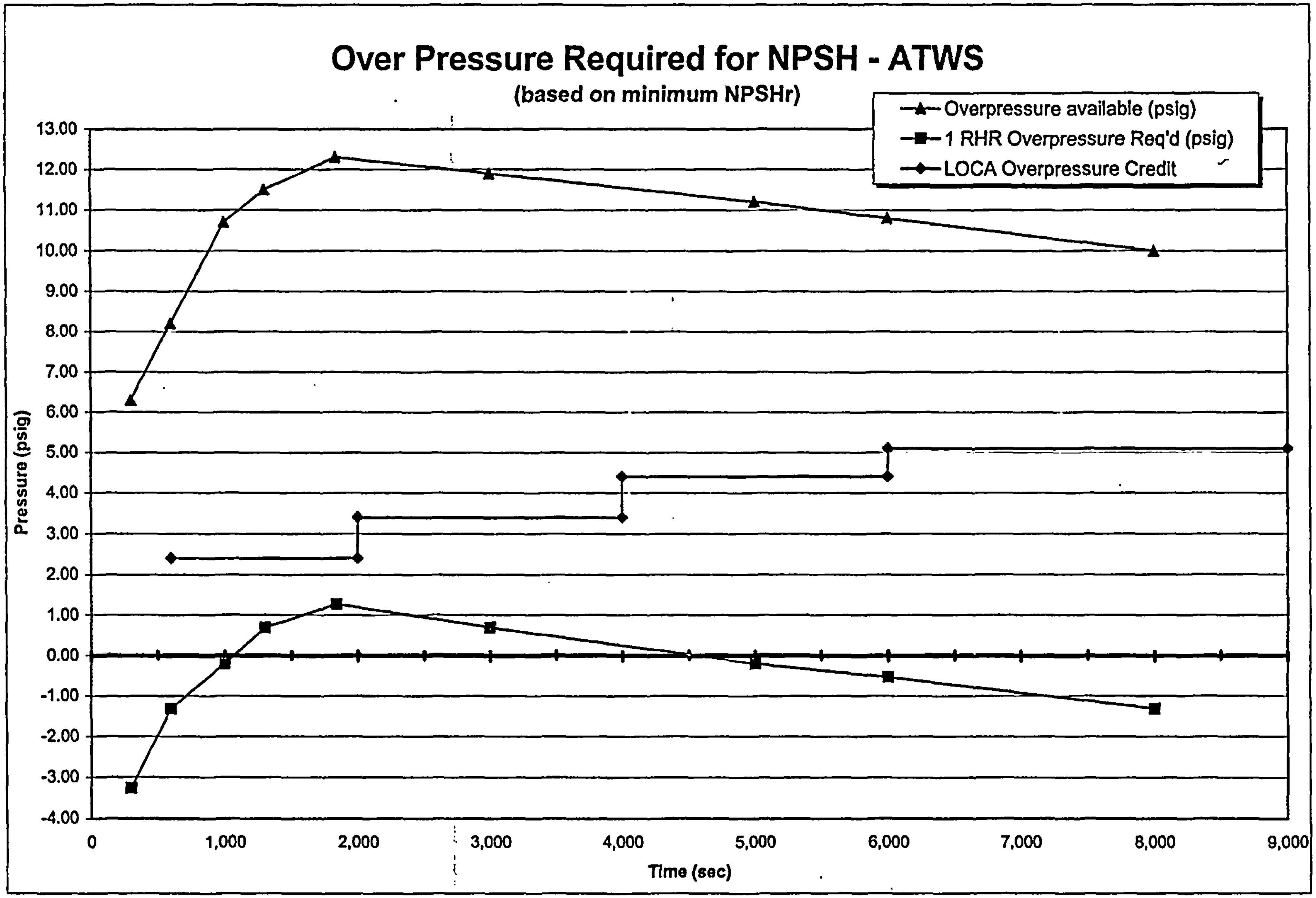
	Q (gpm)	T (F)	P_g (psia)	v_f (cu ft/lb)	Z (ft)	h_f (ft)	h_s (ft)	NPSHA (ft)	NPSHR (ft)	"Clean" Margin (ft)
1 CS	300	90	0.69813	0.016099	12.47	0.0225	0.00	44.9	32.5	12.4
min-flow	300	120	1.6927	0.016204	12.47	0.0225	0.00	42.8	32.5	10.3
≤ 4 hr	300	150	3.7184	0.016343	12.47	0.0225	0.00	38.3	32.5	5.8
	300	164	5.212	0.016410	12.47	0.0225	0.00	34.9	32.5	2.4
	300	181.9	7.836	0.016521	12.47	0.0225	0.00	28.8	32.5	-3.7
	300	190	9.34	0.016572	12.47	0.0225	0.00	25.2	32.5	-7.3
1 CS	1250	90	0.69813	0.016099	12.47	0.39	0.04	44.5	27.0	17.5
min-flow	1250	120	1.6927	0.016204	12.47	0.39	0.04	42.4	27.0	15.4
> 4 hr	1250	150	3.7184	0.016343	12.47	0.39	0.04	37.9	27.0	10.9
	1250	164	5.212	0.016410	12.47	0.39	0.04	34.5	27.0	7.5
	1250	182.6	7.954	0.016530	12.47	0.39	0.04	28.1	27.0	1.1
	1250	184	8.203	0.016535	12.47	0.39	0.04	27.5	27.0.	0.5
	1250	185	8.384	0.016541	12.47	0.39	0.04	27.1	27.0	0.1
2 RHR	700	90	0.69813	0.016099	12.30	0.01	0.00	44.7	30.0	14.7
min-flow	700	120	1.6927	0.016204	12.30	0.01	0.00	42.6	30.0	12.6
≤ 4 hr	700	150	3.7184	0.016343	12.30	0.01	0.00	38.1	30.0	8.1
	700	164	5.212	0.016410	12.30	0.01	0.00	34.7	30.0	4.7
	700	181.9	7.836	0.016521	12.30	0.01	0.00	28.6	30.0	-1.4
	700	190	9.34	0.016572	12.30	0.01	0.00	25.1	30.0	-4.9
2 RHR	5400	90	0.69813	0.016099	12.30	0.57	0.18	44.0	26.0	18.0
min-flow	5400	120	1.6927	0.016204	12.30	0.57	0.18	41.9	26.0	15.9
> 4 hr	5400	150	3.7184	0.016343	12.30	0.57	0.18	37.4	26.0	11.4
	5400	164	5.212	0.016410	12.30	0.57	0.18	34.0	26.0	8.0
	5400	182.6	7.954	0.016530	12.30	0.57	0.18	27.6	26.0	1.6
	5400	190	9.34	0.016572	12.30	0.57	0.18	24.3	26.0	-1.7

Figure 4.2 LOCA – Long Term (1.5 wt. % Containment Leakage & 100% Spray Efficiency)



OPC overpress credit	
(sec)	(psig)
601	2.4
2000	2.4
2001	3.4
4000	3.4
4001	4.4
6000	4.4
6001	5.1
9000	5.1
9001	6.1
40000	6.1
40001	5.6
50000	5.6
50001	5.1
60000	5.1
60001	4.6
70000	4.6
70001	4.1
80000	4.1
80001	3.6
90000	3.6
90001	3.1
110000	3.1
110001	2.6
130000	2.6
130001	2.1
150000	2.1
150001	1.7
170000	1.7
170001	1.3
180000	1.3
200000	1.3
200001	0

Figure 4.3-1


Over Pressure Required for NPSH - ATWS
(based on minimum NPSHr)
Overpressure available (psig)
1 RHR Overpressure Req'd (psig)
LOCA Overpressure Credit
13.00
12.00
11.00
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
Pressure (psig)
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000
9,000
Time (sec)

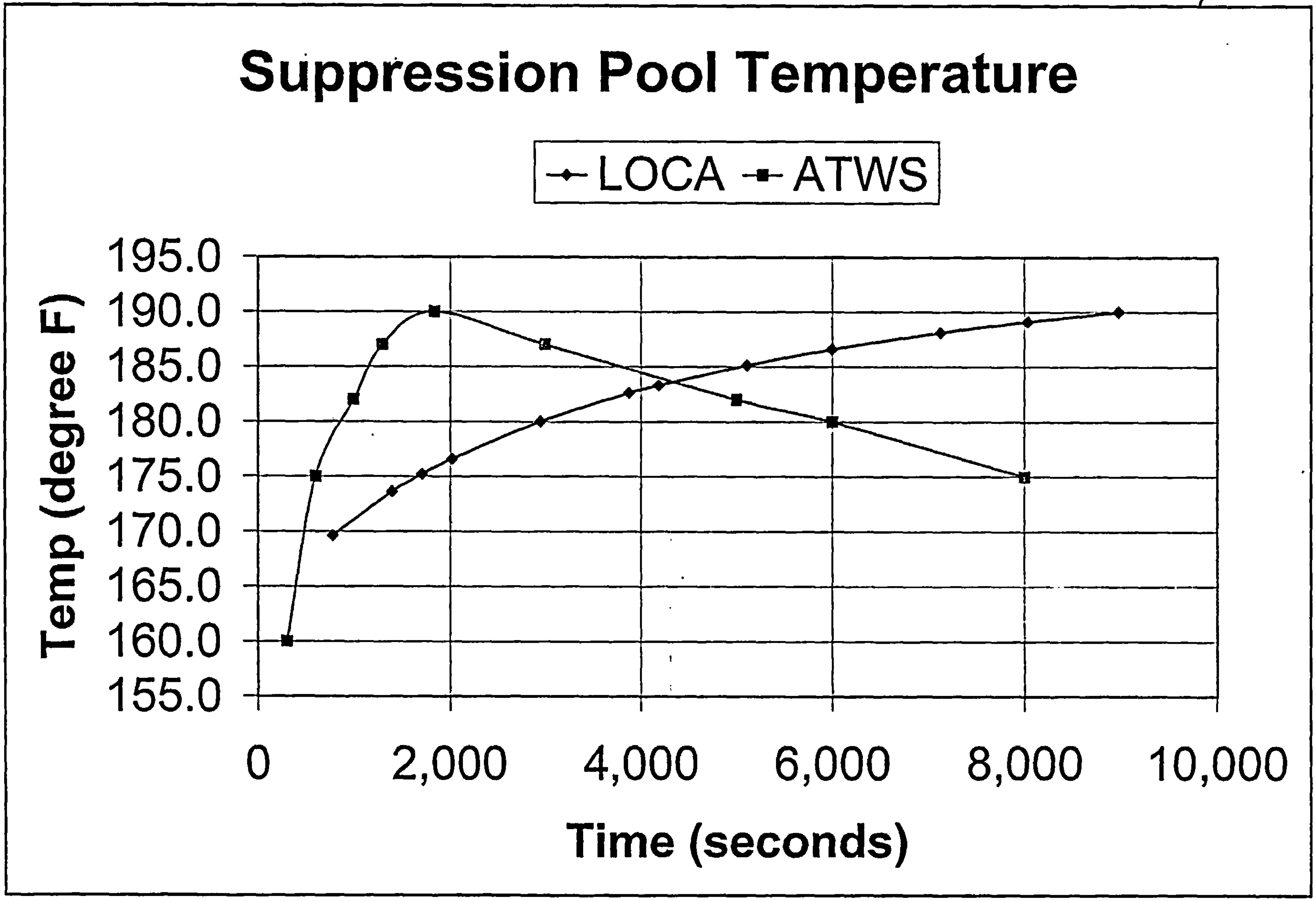

Suppression Pool Temperature
LOCA
ATWS
195.0
190.0
185.0
180.0
175.0
170.0
165.0
160.0
155.0
Temp (degree F)
0
2,000
4,000
6,000
8,000
10,000
Time (seconds)

Figure 4.4-1

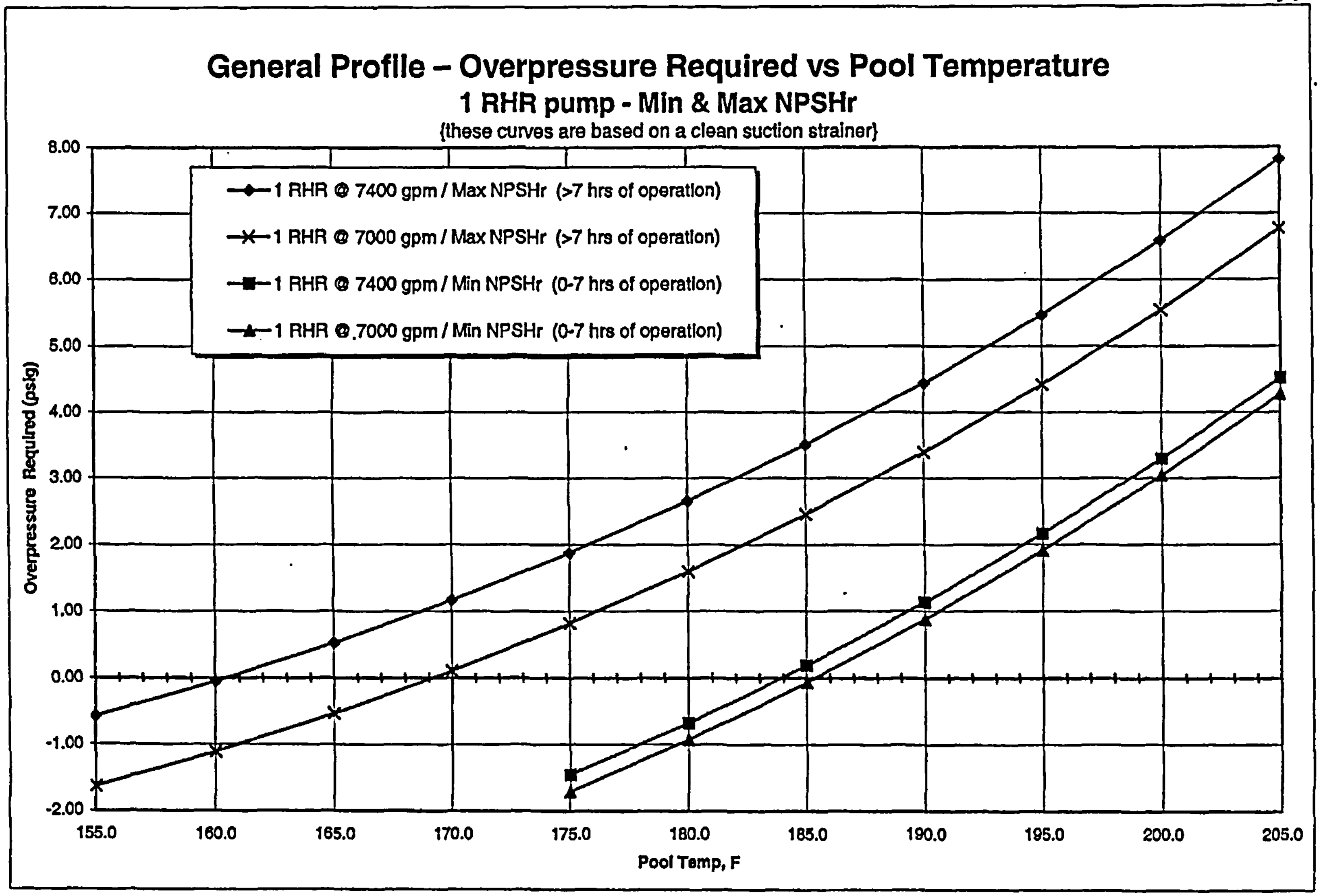

General Profile – Overpressure Required vs Pool Temperature
1 RHR pump - Min & Max NPSHr
{these curves are based on a clean suction strainer}
1 RHR @ 7400 gpm / Max NPSHr (>7 hrs of operation)
1 RHR @ 7000 gpm / Max NPSHr (>7 hrs of operation)
1 RHR @ 7400 gpm / Min NPSHr (0-7 hrs of operation)
1 RHR @ 7000 gpm / Min NPSHr (0-7 hrs of operation)
Overpressure Required (psig)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
155.0
160.0
165.0
170.0
175.0
180.0
185.0
190.0
195.0
200.0
205.0
Pool Temp, F

Figure 4.4-2

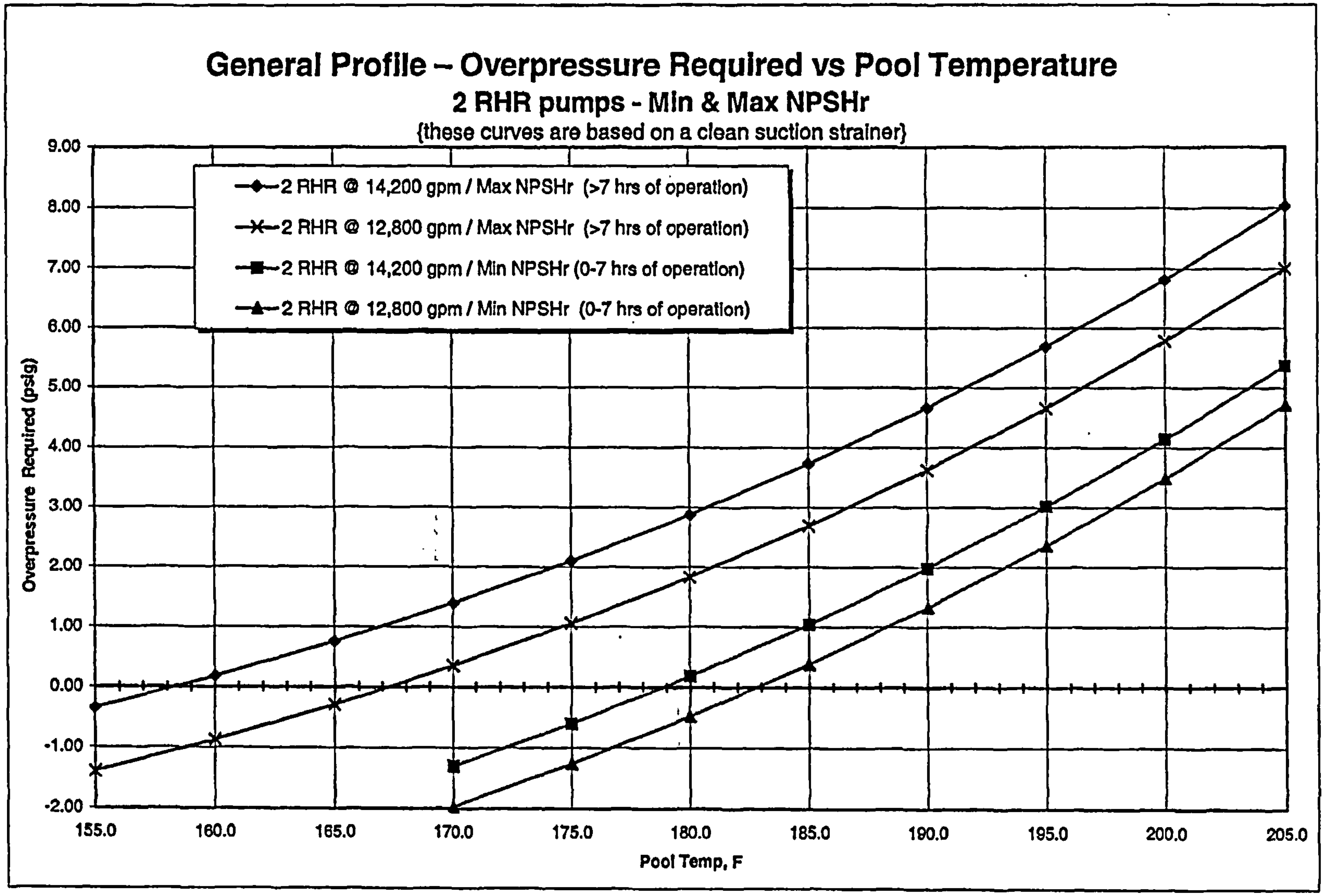

General Profile – Overpressure Required vs Pool Temperature
2 RHR pumps - Min & Max NPSHr
{these curves are based on a clean suction strainer}
2 RHR @ 14,200 gpm / Max NPSHr (>7 hrs of operation)
2 RHR @ 12,800 gpm / Max NPSHr (>7 hrs of operation)
2 RHR @ 14,200 gpm / Min NPSHr (0-7 hrs of operation)
2 RHR @ 12,800 gpm / Min NPSHr (0-7 hrs of operation)
Overpressure Required (psig)
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
155.0
160.0
165.0
170.0
175.0
180.0
185.0
190.0
195.0
200.0
205.0
Pool Temp, F

Figure 4.4-3

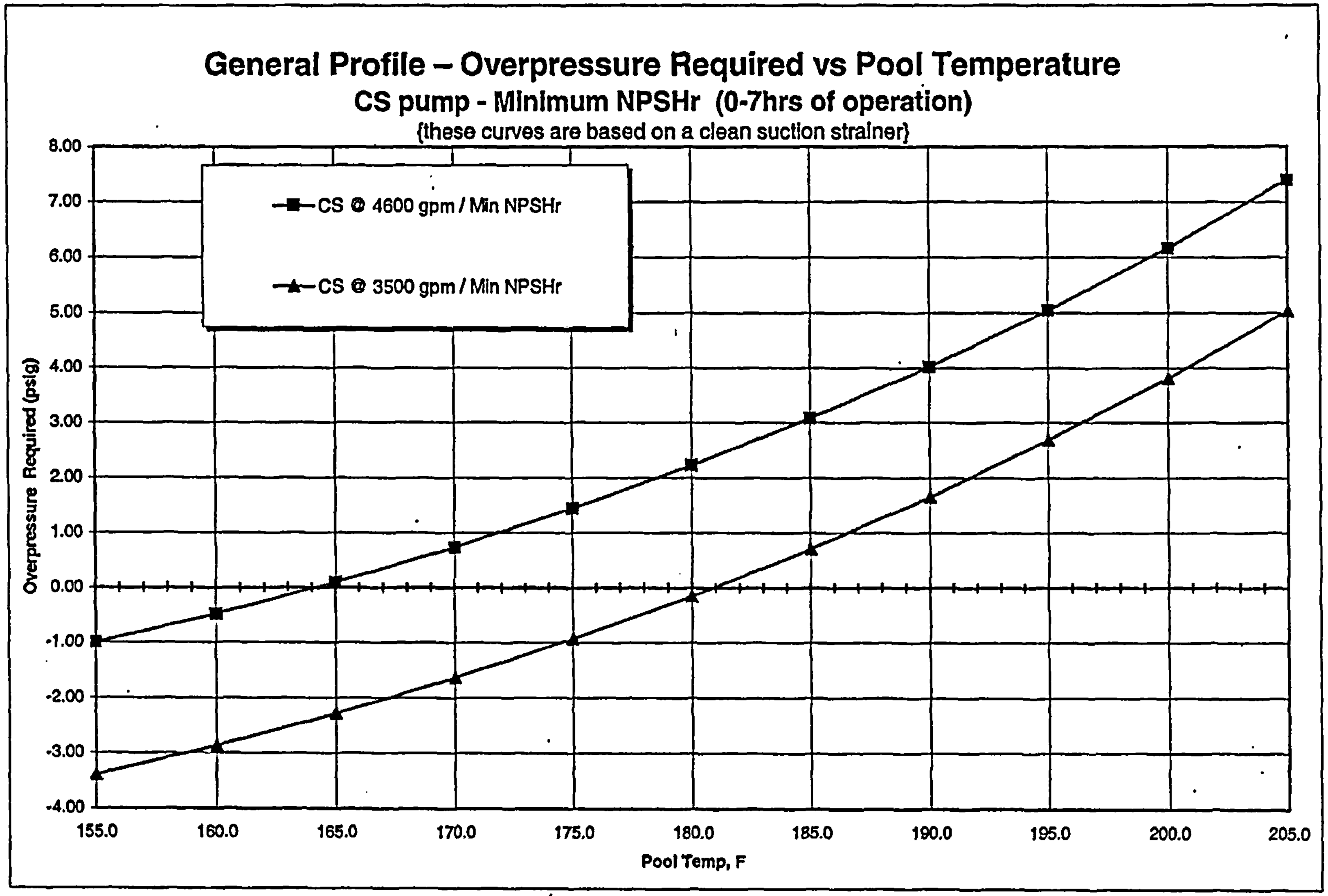
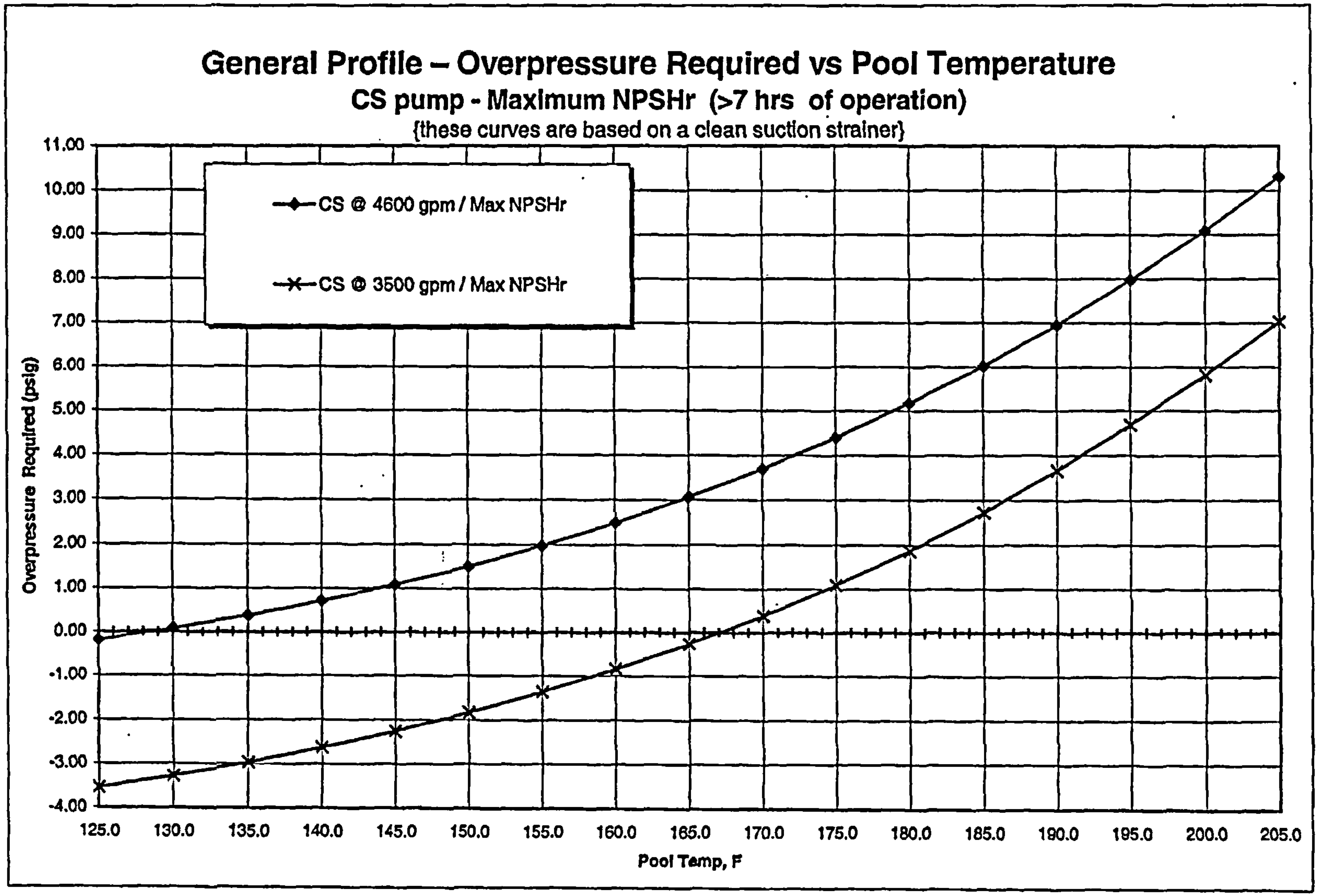

General Profile – Overpressure Required vs Pool Temperature
CS pump - Minimum NPSHr (0-7hrs of operation)
{these curves are based on a clean suction strainer}
CS @ 4600 gpm / Min NPSHr
CS @ 3500 gpm / Min NPSHr
Overpressure Required (psig)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
155.0
160.0
165.0
170.0
175.0
180.0
185.0
190.0
195.0
200.0
205.0
Pool Temp, F

Figure 4.4-4


General Profile – Overpressure Required vs Pool Temperature
CS pump - Maximum NPSHr (>7 hrs of operation)
{these curves are based on a clean suction strainer}
CS @ 4600 gpm / Max NPSHr
CS @ 3500 gpm / Max NPSHr
Overpressure Required (psig)
Pool Temp, F
11.00
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
125.0
130.0
135.0
140.0
145.0
150.0
155.0
160.0
165.0
170.0
175.0
180.0
185.0
190.0
195.0
200.0
205.0

Derivation of strainer debris accumulation equation.

Debris is added to the suppression pool, which is a constant volume, V. The amount of debris, D, is uniformly mixed in the pool, giving a mixture concentration, D/V. The water containing the debris is pumped through a filter, which is assumed to be 100% efficient in removing the debris from the water. The filtered water is returned to the pool. Assuming a flow rate, Q, through the filter, the rate of accumulation of debris on the strainer can be expressed as follows

$$\frac{dD_{strainer}}{dt} = Q\left(\frac{D}{V}\right)$$

The concentration, $\frac{D}{V}$, changes with time as debris is removed. The rate of change of concentration is determined by taking the derivative of (D/V) with respect to time, thus

$$\frac{d(D/V)}{dt} = \frac{1}{V}\frac{dD}{dt} - \frac{D}{V^2}\frac{dV}{dt}$$

Since V = constant, dV/dt = 0. Also, the rate of change of debris in the pool, dD/dt, equals the negative of the rate of accumulation on the strainer. Thus,

$$\frac{d(D/V)}{dt} = -\frac{1}{V}Q\left(\frac{D}{V}\right)$$

$$\frac{d(D/V)}{(D/V)} = -\frac{Q}{V}dt$$

Integrating

$$\int \frac{d(D/V)}{(D/V)} = \int -\frac{Q}{V}\,dt$$

$$\ln\left(\frac{D}{V}\right) = -\frac{Q}{V}t + \text{constant of integration}$$

Initial conditions,

when $t = 0$, $D = D_0$, $\therefore$ constant $= \ln\left(\frac{D_0}{V}\right)$

Substituting

$$\ln\left(\frac{D}{V}\right) = -\frac{Q}{V}t + \ln\left(\frac{D_0}{V}\right)$$

$$\ln\left(\frac{D}{V}\right) - \ln\left(\frac{D_0}{V}\right) = -\frac{Q}{V}t$$

$$\ln\frac{D/V}{D_0/V} = -\frac{Q}{V}t$$

$$\frac{D}{D_0} = e^{-\frac{Q}{V}t} \quad \text{or} \quad D = D_0\, e^{-\frac{Q}{V}t}$$

Now, the amount on the strainer equals the amount removed from the pool, which is $D_0 - D$.

Thus $D_{strainer} = D_0 - D = D_0 - D_0\, e^{-\frac{Q}{V}t}$

or

$$\boxed{\frac{D_{strainer}}{D_0} = \left(1 - e^{-\frac{Q}{V}t}\right)}$$

ITS/VY-00-001
Rev.0

Revised ECCS Suction Strainer Head Loss Assessment for Vermont Yankee

Prepared for
Vermont Yankee Nuclear Power Corporation

Innovative Technology Solutions Corporation
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Albuquerque, NM 87110

October 15, 2000

Prepared By:	Peter K. Mast	Signature	10/15/00 Date
Reviewed By:	Gilbert L. Zigler	Signature	10/16/00 Date

An assessment of ECCS suction strainer head loss for the Vermont Yankee plant was completed in August of 1998 (Calculation DC-A34600.006). Since that time, better information has been obtained on a couple of key parameters in the analysis. These changes are as follows:

- The long-term CS flow rate was determined to be 3500 GPM (previously, a parametric range of 4000-4600 GPM had been considered).
- The long-term pool temperature has been determined to be 185 Deg F.
- The quantity of sludge used for the analysis was reduced by approximately a factor of two.
- Minor changes in fibrous debris distribution.

As a result of the first and fourth of these changes, the distribution of debris on the RHR and CS strainers is changed; a greater fraction of the debris now is deposited on the RHR strainer. Thus, this change would be expected to result in a higher RHR strainer head loss (same flow rate, same temperature, and greater debris quantity) and a lower CS strainer head loss (lower flow rate, same temperature, and lower debris quantity).

The second of these changes, the increased water temperature, and the third of these changes, the reduction in sludge quantity, would tend to reduce head loss for both the CS and RHR strainers, assuming the same assumptions on sludge behavior (filtration) are used in the analysis.

To evaluate the impact of the above changes on strainer head loss, Cases 1 and 3b (the long-term 1-pump RHR and CS analyses, respectively) were reanalyzed. The following table summarizes the debris quantities used in this analysis along with a comparison to those previously used.

Parameter	Units	RHR System		CS System	
		Old Case 1	New Case 1	Old Case 3b	New Case 3b
Flow Rate	GPM	7400	7400	4000	3500
Water Temperature	Deg F	173	185	173	185
Nukon	Lbm	258	256	152	122
Fibermat	Cu-Ft	9.6	10	5.7	5
TempMat	Lbm	20.5	31	12.1	15
Armaflex	Cu-Ft	0 (1)	0 (1)	0 (1)	0 (1)
Sludge (dry)	Lbm	546	271	322	129
Rust	Lbm	35.3	35	20.8	17
Qualified Coat	Lbm	61	60	36	29
Unqual Coat – IOZ	Lbm	70	70	42	42
Unqual Coat – Epox	Sq-Ft	0 (2)	0 (2)	0 (2)	0 (2)

(1) – This material was shown to float and not impact strainer performance.
(2) – ARL testing showed that this coatings debris did not deposit on strainer.

Using the above distributions of fibrous insulation debris, the total mass of fibrous debris changed from 336 lbm to 347 lbm for Case 1 (RHR) and from 198 lbm to 167 lbm in Case 3b (CS). Aside from the change in the particulate debris quantities specified above, and the change in flow rate for Case 3b, all other analysis parameters used in this reassessment are identical to those used in the previous calculations. This includes a reduction of 50% in the quantity of sludge, qualified coatings debris, and IOZ debris being deposited on the strainer due imperfect filtration of this material by the relatively thin fiber mat.

The results of these analyses, along with a comparison to the previously calculated results, are presented in the following table.

Calculated Parameter	Units	RHR System		CS System	
		Old Case 1	New Case 1	Old Case 3b	New Case 3b
Head Loss	Ft water	0.33	0.26	0.21	0.08
Debris Thickness	inches	1.9	2.1	2.6	2.2

0.31 VYC 1924

Table of Contents

1.0 Introduction

The objective of this CCN is to determine the available NPSH for the Residual Heat Removal (RHR) and Core Spray (CS) pumps at design flow during the most limiting torus heat-up scenario and compare the available NPSH (NPSHa) to the required NPSH (NPSHr).

2.0 Analysis

For each of the RHR and CS pumps, NPSHa as a function of time will be determined based on methods developed in VYC-808, Revision 6. NPSHa varies with time only because the fluid temperature does so during the transient. The limiting torus temperature profile from VYC-1628F (run15) is used for this analysis. The NPSHa for each pump is then plotted against the vendor's allowable NPSHa to demonstrate pump operability.

The vendor's allowable NPSHa are shown in Figures 2.1-1 (RHR Pumps) and 2.2-1 (CS Pumps). For a complete description of these curves, see VYC-808, Revision 6 and its Attachment 5. In summary, the curves show the allowable operating period for a given pump at any NPSHa. Provided the calculated NPSHa for a specific flow rate is, at all times, greater than the corresponding curve for the same flow rate, the pump is considered operable regarding NPSH.

The pump vendor is Sulzer Bingham Pumps, Inc. (SBPI). Their allowable NPSHa are provided for flow rates of 6400, 7000, and 7600 gpm for the RHR pump (VYC-808, Attachment 5). The maximum long-term flow rate of the system is 7400 gpm (VYC-808, Section 3.4). The first step in this calculation is to develop an allowable NPSHa curve at the maximum flow. This is done using the curve fit from VYC-808, Revision 6, Section 2.2.2 for times between 1 and 7 hours, and by linear interpolation between the SBPI curves for 7000 gpm and 7600 gpm beyond 7 hours. The use of a linear interpolation beyond 7 hours is conservative based on the predicted variations among 6400, 7000, and 7600 gpm as shown on the SBPI curves. The curve fit from VYC-808 is:

$$NPSH_{RHR} = 23.0 + \frac{Q - 6400}{1200}\ feet \qquad \text{(Eq. 1.1)}$$

8

The next step is to plot the available NPSH for the limiting torus temperature scenario. The equation for NPSHa – developed in Section 4.2.2.4 of VYC-808 for the RHR pump at 7400 gpm – is:

$$NPSHa_{RHR} = (p_{torus} - p_v)(144)v + Z - H_f - H_D - H_{strainer} \qquad \text{(Eq. 1.2)}$$

where, p_{torus} = torus pressure (14.7 psia)
p_v = vapor pressure of water at temperature (psia)
144 = conversion factor
v = specific volume of water at temperature (ft^3/lbm)
Z = elevation head (12.42 ft)
H_f = friction head loss (2.61 ft)
H_D = strainer debris head loss (0 ft)
$H_{strainer}$ = clean strainer head loss (0.35 ft)

The method of solution for the Core Spray pump is the same as that for the RHR pump, but with the following exceptions. SBPI's allowable NPSHa are provided for flow rates of 3000, 3500, and 4600 gpm for the CS pump (attached). The maximum long-term flow rate of the system is 3500 gpm (VYC-808, Section 3.4). Therefore, the minimum allowable NPSH is known and needn't be derived.

The equation for NPSHa developed in Section 4.2.3.4 of VYC-808 for the CS pump at 3500 gpm is also Equation 1.2, but with the following values: 8

p_{torus} = torus pressure (14.7 psia)
p_v = vapor pressure of water at temperature (psia)
144 = conversion factor
v = specific volume of water at temperature (ft^3/lbm)
Z = elevation head (12.59 ft)
H_f = friction head loss (3.06 ft)
H_D = strainer debris head loss (0 ft)
$H_{strainer}$ = clean strainer head loss (0.32 ft)

3.0 Inputs/Outputs

Design inputs used in this calculation are:

- the temperature data from VYC-1628F for the limiting torus heat-up scenario (run15), and
- an adder to the above temperatures that accounts for event conditions that were not modeled. From Reference 19, the most limiting adder is 0.9°F.

The assumptions used in this calculation are the same as those in VYC-808, Revision 6.

4.0 Results

4.1 RHR Pump

Figure 2.1-1 shows the SBPI allowable times at NPSH for RHR pump flow rates of 6400, 7000, and 7600 gpm. The same curve for the design flow rate of 7400 gpm is also shown. It is derived by using Equation 1.1 for times between 1 hour and 7 hours, and by linear interpolation between the SBPI curves for times beyond 7 hours. The data points are:

Time (hours)	NPSHa @ 7000 gpm (feet)	NPSHa @ 7600 gpm (feet)	NPSHa @ 7400 gpm (feet)
1	N/A Use Equation 1.1		23.8
7	N/A Use Equation 1.1		23.8
13.5	25.0	28.0	27.0
21	28.5	31.6	30.6
100	29.5	32.75	31.7
8000	29.5	32.75	31.7

8

The limiting NPSHa curve for the RHR pump is determined with Equation 1.2 and the limiting torus water temperature profile from VYC-1628F, run15 (Reference 5). The temperatures from run15 are increased by 0.9°F to account for event conditions that were not modeled (Reference 19). The data points for the curve are shown in Table 2.1-1. Values for p_v and γ are interpolated from the saturated steam tables.

The limiting NPSHa falls above the allowable curve at the design flow rate for all times. Therefore, the pump's operability is not compromised.

Table 2.1-1
RHR Pump NPSHa During the Limiting Torus Temperature Transient

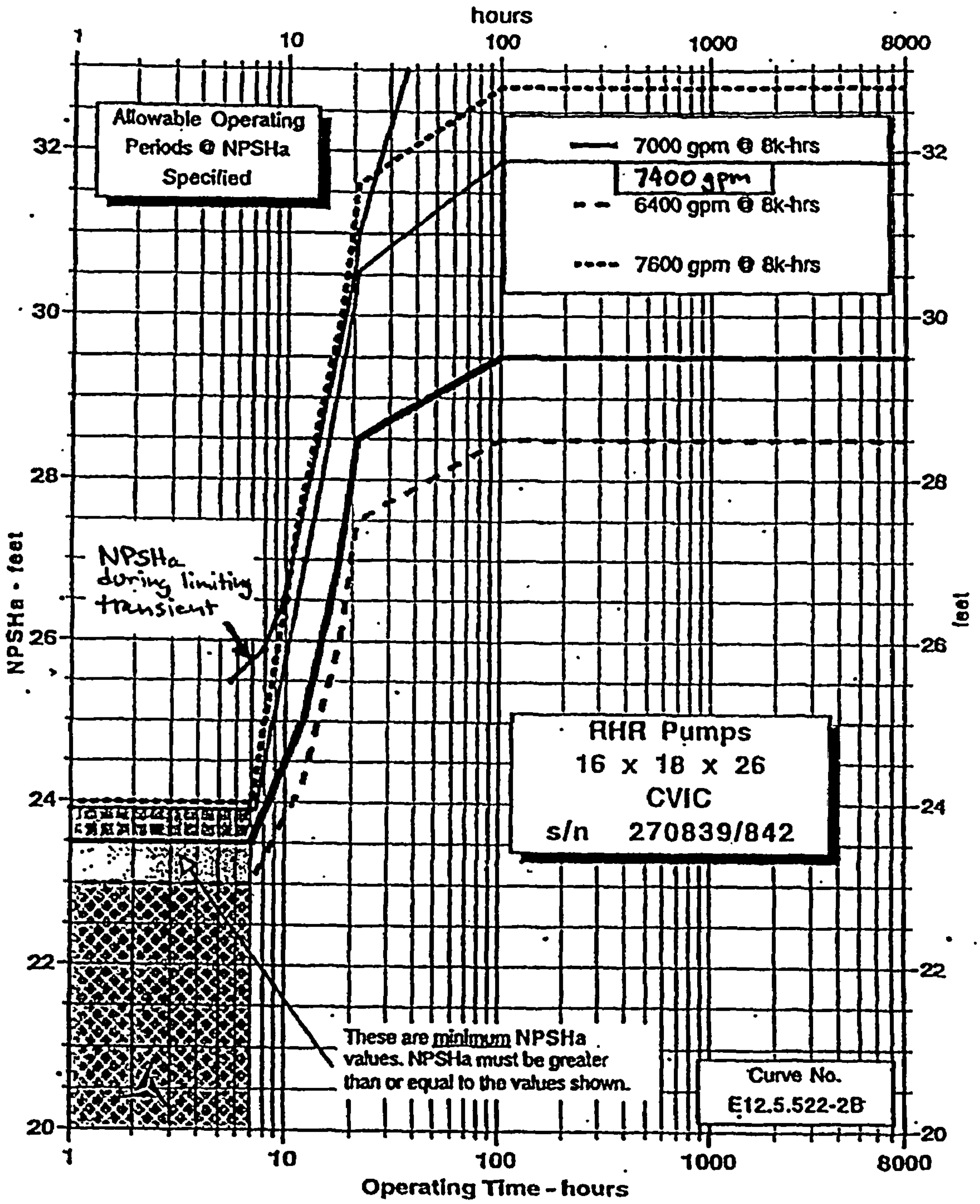
Time	Temperature (°F)		p_v (psia)	v (ft^3/lbm)	NPSHa (ft)
	From run15	+0.9°F			
5.6 hrs (20,240 sec)	181.7	182.6	7.956	0.016525	25.5
8 hrs (28,797 sec)	180.9	181.8	7.819	0.016521	25.8
10 hrs (36,050 sec)	179.2	180.1	7.529	0.016511	26.5
20 hrs (72,054 sec)	167.7	168.6	5.807	0.016443	30.5
21 hrs (75,554 sec)	166.7	167.6	5.555	0.016432	31.1
100 hrs (360,079 sec)	138.1	139.0	2.816	0.016288	37.3

Superceded.

8

Figure 2.1-1

RHR Pump Allowable Operating Periods @ NPSHa Specified



4.2 CS Pump

Figure 2.2-1 shows the SBPI allowable times at NPSH for CS pump flow rates of 3000, 3500, and 4600 gpm.

The limiting NPSHa curve for the CS pump is determined with Equation 1.2 and the limiting torus water temperature profile from VYC-1628F, run15 (Reference 5). The temperatures from run15 are increased by 0.9°F to account for event conditions that were not modeled (Reference 19). The data points for the curve are shown in Table 2.2-1. Values for p_v and v are interpolated from the saturated steam tables.

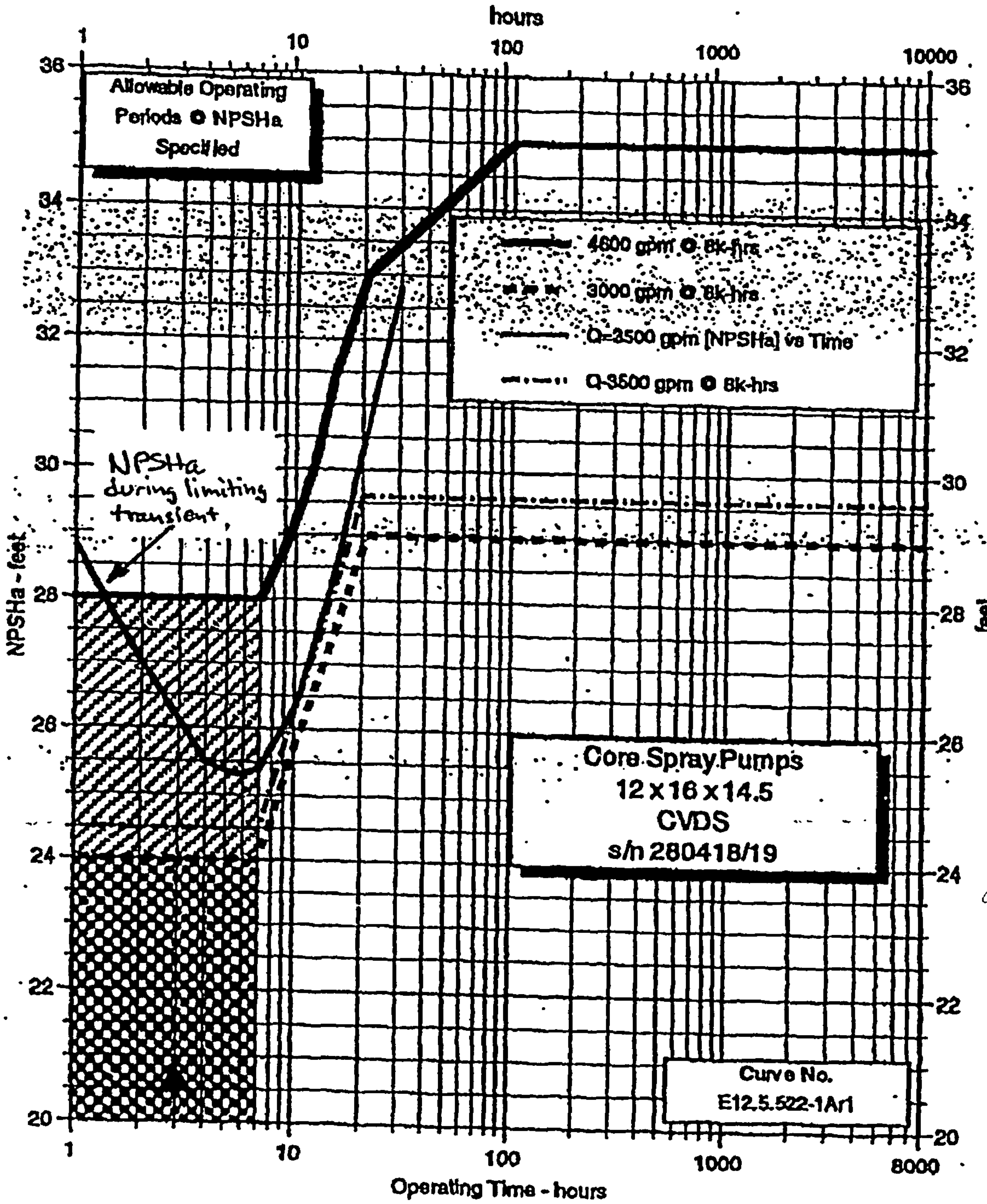
The limiting NPSHa falls above the allowable curve at the design flow rate for all times. Therefore, the pump's operability is not compromised.

Table 2.2-1
CS Pump NPSHa During the Limiting Torus Temperature Transient

Time	Temperature (°F) From run15	Temperature (°F) +0.9°F	p_v (psia)	v (ft³/lbm)	NPSHa (ft)
1 hrs (3,595 sec)	172.3	173.2	6.449	0.01647	28.8
2 hrs (7,203 sec)	177.2	178.1	7.204	0.016499	27.0
4 hrs (14,410 sec)	181.0	181.9	7.836	0.016521	25.5
5.6 hrs (20,240 sec)	181.7	182.6	7.956	0.016525	25.3
7 hrs (25,194 sec)	181.4	182.3	7.904	0.016524	25.4
10 hrs (36,050 sec)	179.2	180.1	7.529	0.016511	26.3
15 hrs (54,052 sec)	173.4	174.3	6.613	0.016476	28.4
20 hrs (72,054 sec)	167.7	168.6	5.807	0.016443	30.3
30 hrs (108,056 sec)	158.7	159.6	4.697	0.016393	32.8

8

Figure 2.2-1
CS Pump Allowable Operating Periods @ NPSHa Specified



5.0 Conclusion

The limiting NPSH available for the RHR and CS pumps have been determined for the respective design flow rates during the limiting torus temperature transient. In both cases, the limiting NPSHa falls above the respective allowable NPSH for all times. Therefore, the pumps' operability are not compromised.

8

Attachment – Letter, Sulzer-Bingham to D. E. Yasi, VYNPC, March 26, 1999

Telefax

SULZER PUMPS
Division of Sulzer Roteq

Sulzer Bingham Pumps Inc.
Field Engineering
Kenny Thomson
Manager
2800 N.W. Front Avenue
Portland, OR 97210-1502
U.S.A.

Tel. (503) 226-5434
Fax (503) 226-5383

Date: 26 March, 1999

To: Mr. Dan Yasi
VERMONT YANKEE DESIGN ENGINEERING OFFICE
Massachusetts

Fax: 8-1-978-568-3732

Pages: 1 (including this one)

Subject: Serial #270839/842 – 280418/419
F-97-10782 30P59
Yankee PO QA42125

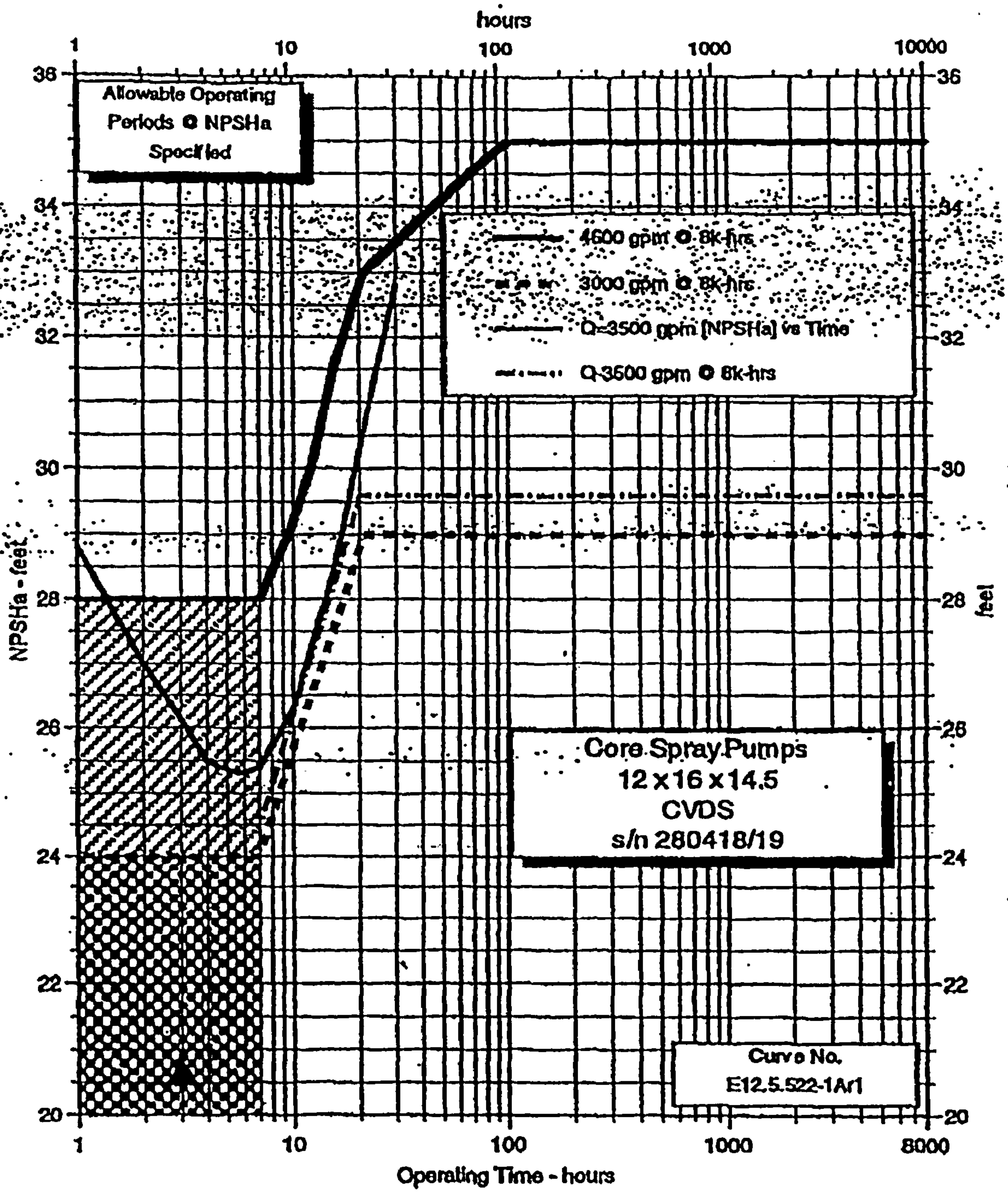
With reference to your letter of 12 March 99, based on original NPSHr curve, test data the period of operation will nearly equal the 3000 gpm curve.

Please see curve (E12.6.522-1Ar1) attached.

Kind Regards,

Kenny Thomson

Kla


hours
1
10
100
1000
10000
Allowable Operating Periods @ NPSHa Specified
4600 gpm @ 8k-hrs
3000 gpm @ 8k-hrs
Q=3500 gpm [NPSHa] vs Time
Q-3500 gpm @ 8k-hrs
NPSHa - feet
feet
36
34
32
30
28
26
24
22
20
Core Spray Pumps
12 x 16 x 14.5
CVDS
s/n 280418/19
Curve No.
E12.5.522-1Ar1
1
10
100
1000
8000
Operating Time - hours

ATTACHMENT 4

~~VY CALCULATON CHANGE NOTICE (CCN)~~

~~CCN Number: 1~~ Calculation Number: VYC-0808 Rev. Number: ~~6~~ 7

Calculation Title: Core Spray and Residual Heat Removal Pump Net Positive Suction Head Margin Following a Loss of Coolant Accident

Initiating Document: STP 2000-021

VYDC/MM/TM/Spec. No./ other

Safety Evaluation Number: N/A

Superseded Document: N/A

Implementation Required: ☐ Yes ☒ No

Reason for Change:

STP 2000-021 [1] being performed in support of the reactor water chemistry project and noble metals injection proposes to operate the RHR system in an atypical mode. Specifically, it is proposed to operate both trains of RHR, either with one pump operating in each train or two, taking a suction from the common shutdown cooling line off of recirculation loop "A" and injecting back into the vessel via the respective recirculation loop injection lines.

These modes of operation are considered a departure from normal shutdown cooling in that shutdown cooling normally utilizes only one train of RHR with a single pump operating as opposed to two trains of RHR [2]. This CCN documents the NPSH margin for shutdown cooling operation using either one or two trains.

Description of Change: See attached.

Technical Justification for Change: See attached.

Conclusion:

Minimum NPSH margins for various modes of SDC are calculated:

- single train of RHR with one pump operating at 7600 gpm is 50.8 ft
- two trains of RHR with one pump operating at 7600 gpm in each loop is 48.2 ft
- two trains of RHR with two pumps (each) operating at 7300 gpm (each) in each loop is –15.5 ft
- two trains of RHR with two pumps (each) operating at 7300 gpm (each) in each loop with RWCU operating is –16.0 ft
- two trains of RHR with two pumps (each) operating at 6625 gpm (each) in each loop with RWCU operating is 0.5 ft

No specific 50.59(a)(1) or (a)(2) is required as this ~~CCN~~ attachment only validates existing NPSH margins. This ~~CCN~~ attachment does not justify any additional modes of operation (though may be used as a basis for other documents doing so). | 7

Prepared By/Date	Interdiscipline Review By/Date	Independent Review By/Date	Approved By/Date
[signature] 2/13/01 Carl Fago	N/A	[signature] 2/13/01 Bruce Slifer	[signature] * 2/26/01 Jim Callaghan

Installation Verification / Final Turnover to DCC: * STP 2000-021 controls flows to acceptable limits based on NPSH Results identified above.

Open Items Associated with CCN ☐ Yes ☒ No ☐ Closed (Section 2.3.2)

Installation Verification (Section 2.3.4)

☒ Calculation accurately reflects plant as-built configuration, OR

☐ N/A, calculation does not affect plant configuration

Resolution of documents identified in the Design Output Documents Section of VYAPF 0017.07 (Section 2.3.6)

Carl D. Fago	[signature]	2/26/01
Print Name	Signature	Date

Total number of pages in package including all attachments 16

Note: VYAPF 0017.07 should be included immediately following this form.

ATTACHMENT 4

VY CALCULATION DATABASE INPUT FORM

VYC-0808 / ~~1~~	~~6~~ 7	N/A	N/A
VY Calculation/CCN #	Revision #	Vendor Calculation #	Revision #

Vendor Name: N/A PO Number: N/A

Originating Department: Fluid Systems

Critical References Impacted: ☐ FSAR ☐ DBD ☐ Reload "Check" the appropriate box if any critical document is identified in the tables below.

EMPAC Asset/Equipment ID Number(s): P-10-1A/B/C/D

EMPAC Asset/System ID Number(s): 10, 14

Keywords: Residual Heat Removal (RHR), Net Positive Suction Head (NPSH), Pump, Shutdown Cooling (SDC)

For Revision/CCN only: Are deletions to General References, Design Input Documents or Design Output Documents required? ☐ Yes† ☒ No

General References

*Reference #	** DOC #	REV #	*** Reference Title (including Date, if applicable) (See App. A, Section 3.2.7 for Guidance)	**** Affected Program	Critical Reference (√)
1.	STP 2000-021	Draft	Noble Metals Injection Process		
2.	OP-2124	49	Residual Heat Removal System		
19	OP-2112	30	Reactor Water Clean-Up System		

ATTACHMENT 4

Page 2

Design Input Documents – The following documents provide design input to this calculation. (Refer to Appendix A, section 4)

*Reference #	** DOC #	REV #	*** Reference Title (including Date, if applicable) (See App. A, Section 3.2.7 for Guidance)	**** Affected Program	Critical Reference (√)
3.	VYC-808	6	Core Spray and Residual Heat Removal Pump Net Positive Suction Head Margin Following a Loss of Coolant Accident		
4.		202	VY Technical Specifications, Section 4.5.A		
5.	G191172	59	VY DWG, Flow Diagram – Residual Heat Removal System		
6.	5920-3773 Sht 2	12	VY DWG, Assembly – Reactor for Nuclear Boiler		
7.	5920-13	2	VY DWG, Arrangement – Primary and Secondary Containment		
8.	G-191211	16	VY DWG, RHR System Piping		
9.	N/A	N/A	Crane Flow of Fluids, Technical Paper No. 410		
10.	5920-6637	0	VY DWG, Residual Heat Removal Piping – Doc of As-Built Dims		
11.	5920-9283	4	VY DWG, Residual Heat Removal (RHR) Part 5, Sheet 1		
12.	5920-9284	3	VY DWG, Residual Heat Removal (RHR) Part 5, Sheet 2		
13.	5920-9286	4	VY DWG, Residual Heat Removal (RHR) Part 6, Sheet 2		
14.	5920-9285	4	VY DWG, Residual Heat Removal (RHR) Part 6, Sheet 1		
15.	VYC-1628	0	Torus Temperature and Pressure Response to Large Break LOCA and MSLB Accident Scenarios		
16.	5920-6620	0	VY DWG, Recirculation Loop Piping – Doc of As-Built Dims		
17.	VYS 98/97	N/A	Memorandum, Swenson & Rainey to Mills, "Evaluation of Maximum Expected Flows for ECCS Strainer Replacement", dated August 28, 1997		
18	G191210	18	VY DWG, RHR System Piping Section		

Design Output Documents – This calculation provides output to the following documents. (Refer to Appendix A, section 5)

*Reference #	** DOC #	REV #	Document Title (including Date, if applicable)	**** Affected Program	Critical Reference (√)

* Reference # - Assigned by preparer to identify the reference in the body of the calculation.

** Doc # - Identifying number on the document, if any (e.g. 5920-0264, G191172, VY6-1286)

*** Reference Title - List the specific documentation in this column. "See attached list" is not acceptable. Design Input/Output Documents should identify the specific design input document used in the calculation or the specific document affected by the calculation and not simply reference the document (e.g., VYDC, MM) that the calculation was written to support.

**** Affected Program - List the affected program or the program that reference is related to or part of. If the reference is FSAR, DBD or Reload (IASD or OPL), check Critical Reference column and check FSAR, DBD or Reload, as appropriate, on this form (above).

† If "yes", attach a copy of "VY Calculation Data" marked-up to reflect deletion (See Section 3.1.8 for Revision and 5.2.3.18 for CCNs).

ATTACHMENT 4

Page ____ of ____

VY CALCULATION REVIEW FORM

Calculation Number: VYC-0808 Revision Number: ~~6~~ 7 CCN Number: ~~1~~

Title: Core Spray and Residual Heat Removal Pump Net Positive Suction Head Margin Following a Loss of Coolant Accident

Reviewer Assigned: ____________ Required Date: N/A

☐ Interdiscipline Review ☒ Independent Review

Comments*	Resolution
Reviewed in accordance with AP 0017 and have no comments.	N/A

[signature] / ________
Reviewer Signature Date

[signature] / ________
Calculation Preparer (Comments Resolved) Date

Method of Review:
☒ Calculation/Analysis Review
☐ Alternative Calculation
☐ Qualification Testing

N/A / ________
Reviewer Signature (Comments Resolved) Date

*Comments shall be specific, not general. Do not list questions or suggestions unless suggesting wording to ensure the correct interpretation of issues. Questions should be asked of the preparer directly.

ATTACHMENT 4

Table of Contents

1.0 Introduction

This purpose of this ~~CCN~~ attachment is to add an evaluation of RHR pump NPSH margin while in the shutdown cooling (SDC) mode of operation. Several modes are evaluated: | 7

- one RHR train in service with one pump operating
- two RHR trains in service with one pump operating per train
- two RHR trains in service with two pumps operating per train

2.0 Methodology

Available NPSH is calculated using the equation:

$$NPSH_a = (p_{Vessel} - p_v)(144)v + Z - H_f$$ [Ref. 3, pg. 13]

where: p_{Vessel} = Reactor vessel pressure, psia
p_v = vapor pressure of pumped fluid, psia
v = specific volume of pumped fluid, ft^3/lbm
Z = height of fluid above pump suction, ft
H_f = friction head loss in suction line, ft

For this particular case, the conservative assumption is $p_{Vessel} = p_v$ based on the highest possible fluid temperature conditions in the vessel, saturated liquid. Therefore, the $NPSH_a$ is simply the difference between the elevation head and the friction loss to the pump suction.

From the shutdown cooling connection on recirculation loop "A" to the RHR pump suction, the friction losses will be calculated by summing the components and pipe lengths from piping isometrics. Simplifying (and conservative) assumptions regarding certain component form losses will be made to simplify the calculation. The total L/D for this section will be determined for each pump. The friction loss for the pump with the highest L/D will be used for the NPSH calculation.

From the water source (reactor vessel) down through the downcomer outside the core shroud, past the jet pumps and into the recirculation suction nozzle at the reactor vessel and through recirculation loop "A" to the shutdown cooling connection, the friction losses will be calculated based on the results from an existing detailed, steady-state RELAP model of the reactor vessel.

The total head loss is calculated as follows:

$$h_L = 0.00259 \cdot f \frac{L}{D} \frac{Q^2}{d^4}$$ [9, pg. 3-4]

where: h_L = head loss, ft
f = friction factor, nominally 0.012 for the pipe sizes relevant to this calculation [9, pg. A-26]
$\frac{L}{D}$ = equivalent length-to-diameter ratio
Q = flow rate, gpm
d = pipe inside diameter, inches

Available and required NPSH for the RHR pumps has previously been calculated in VYC-808 Rev. 6 [3] when taking suction on the torus.

3.0 Assumptions

The following assumptions are made to facilitate a simple calculation of NPSH during SDC. The assumed conditions are chosen to bound potential SDC operations when in hot shutdown (>212°F).

1. The pumped liquid is at saturated conditions (i.e. $T_f = T_{sat}$). This minimizes the $NPSH_a$ which is conservative.
2. Maximum single pump flow of 7600 gpm based on the Technical Specification vessel-to-vessel requirement for RHR pump flow (7450 gpm +/- 150 gpm) (4.5.A.1.c) [4].
3. Maximum two pump flow (in one loop) of 14,600 gpm based on:
   - single pump, vessel-to-vessel is 7600 gpm (above) and torus-to-torus is 7400 gpm [17] for a difference of 200 gpm
   - two pump, torus-to-torus is 14,200 gpm [17]
   - therefore, maximum flow for two pump, vessel-to-vessel is 14,200 + 200 gpm *2 = 14,600 gpm
4. Reactor vessel water level is assumed to be at least 155 inches above TAF. This represents a "minimum" water level needed to preserve the NPSH margins calculated herein.
5. In calculating the system L/D, all 90° elbows are assumed to be short-radius (r/d = 1) elbows vice long-radius elbows. This is a simplifying assumption that maximizes the head loss and minimizes the $NPSH_a$.
6. Component L/D values (used in Tables 1 through 4) are obtained from previously determined values in VYC-0808 Rev. 6, Attachment 7. Also, all valves in the analyzed flow paths are gate valves. [5]
7. Branch lines of a diameter less than half of the main run diameter will be ignored (i.e. treated as straight pipe). The losses from such a branch line are not significant when compared to the total system losses.
8. Fluid viscosity is taken at standard temperature and pressure. Actual viscosity at the higher temperature will be lower than at standard temperature. Therefore, the form losses are overestimated (conservative).
9. RWCU flow is assumed to be 130 gpm (65 gpm for each filter demineralizer unit) [19].
10. The head loss through the portion of the vessel downcomer above the jet pump nozzles is negligible. This head loss component is very small when compared with the overall head loss and other conservative treatments in the calculation.

4.0 Analysis

- **Elevation Head**

The elevation head is simply the difference between the water level in the vessel, assumed to be at 155" above TAF and the elevation of the RHR pump suction.

TAF is defined as 351.5" above the vessel invert [6]. The vessel invert is at elevation 266'-11" [7]. Therefore, the water elevation at 266'-11" + 351.5" + 155" = 309.125 ft.

The elevation of the RHR pump suction is 215'-11" [8] (213'-9" + 2'-2").

Therefore, the total fluid elevation head is at least 93.2 ft (309.125 ft – 215.917 ft).

- **Limiting Pump L/D**

The total L/D for each pump is calculated using a summary of piping lengths and components. The summary for each pump is provided on Tables 1 through 4. Included in these tables are component L/D values per Assumption #6.

By inspection, the limiting line-up is SDC using the "D" RHR pump with a total suction-side L/D of 712.1.

- **Reactor Vessel and Recirculation Line Losses**

The previously calculated L/D does not include any losses in the reactor vessel or recirculation lines. Due to the complex nature of the geometry, the losses are not readily calculated using the standard methods presented in Crane [9]. However, a detailed RELAP model of the reactor vessel and recirculation loops has been previously developed and used for detailed VY LOCA analyses. The model is of sufficient detail that the pressure drop from some arbitrary point in the vessel to some point in the "A" recirculation loop can be approximated based on a steady-state RELAP solution. The static head difference can then be determined and subtracted leaving the unrecoverable form losses for a given flow. The losses can then be scaled to the flow rates of interest and added to the total losses for determining the NPSH.

The steady state run from VYC-1628 Rev. 0 [15] will be used as the baseline case for determining pressure drop. Figure 2.2 from VYC-1628 provides the RELAP nodalization for the baseline case. For convenience, node 274, corresponding to the top of the jet pump will be taken as the upstream location. The SDC suction is nine feet below the recirculation suction nozzle [16]. Therefore, node 314, extending 11.4198 ft below the recirculation suction nozzle (see Table 5), will be the endpoint for the vessel pressure drop calculation. It is noted that the pressures reported in RELAP5YA output correspond to the center of the given node. Therefore, the total pressure drop and head loss do not correspond exactly to the SDC connection. However, the difference, 2.4198 ft of 28-inch pipe represents a negligible head loss when compared with the total head loss (and the total head loss in the vessel is small to begin with) and can be safely ignored.

The nodalization summary and results are shown in Table 5. The node data (pressure, temperature, flow, elevation) are taken from the last major edit of the RELAP output file labeled "*r5bavss1.o*" contained on microfiche "*028YQ*". Nodes with a zero elevation difference are not included in the summary (but their effect on form loss is included in the calculated pressures from RELAP).

The pressure due to static head is calculated from the equation:

$$P_2 = P_1 + \left(Z_1/2 + Z_2/2 \right) \cdot \frac{\rho}{144} \cdot \frac{g}{g_c}$$

where P = pressure at the node center, psi
Z = node elevation difference, ft
ρ = fluid density, lbm/ft3
g = gravitational acceleration constant, 32.2 ft/s^2
g_c = conversion constant, 32.2 ft-lbm/lbf-s^2

The flow loss is calculated from the equation:

$$h_L = (P_{static} - P_{RELAP}) \cdot \frac{144}{\rho}$$

The resultant flow loss from the top of the jet pumps to the SDC connection is taken as 9.5 ft for a flow of 7201.6 lbm/sec or 68310.5 gpm at a density of 47.318 lbm/ft^3.

Table 5 – RELAP Summary of Vessel Downcomer and Recirculation Line Losses

Density = 47.318 lb/ft^3 Flow = 7201.6 lbm/sec

RELAP Node	Height ft	Head psi	Head ft	Pressure, static only	Flow Loss ft
274	3.796	1051.9	3201.2	1051.9	0.00
276	3.6417			1053.1	
278	3.8542			1054.4	
280	2.58	1053.2	3205.1	1055.4	6.73
314	11.4198	1054.6	3209.4	1057.7	9.47

- **Single-Train Head Loss**

The resulting maximum suction head loss during SDC using one RHR pump (without RWCU) is:

$$h_L = 0.00259 \cdot 0.012 \cdot 712.1 \cdot \frac{7600^2}{19.25^4} + 9.5 \cdot \left(\frac{7600}{68310.5} \right)^2$$
$$= 9.4\ ft$$

The resultant $NPSH_a$ would be 83.8 ft (93.2 ft – 9.4 ft).

- **Dual-Train Head Loss – One Pump per Train**

For the shutdown cooling with two trains of RHR in operation and one pump operating in each train (without RWCU flow), the NPSH margin is calculated based on double the RHR flow rate for the combined suction portion of the piping. Table 6 provides the take-off summary differentiating between the common suction and the separate loops. For conservatism, the branch connection where the flow separates is assumed to see full flow. The L/D for the combined suction is 311.4 and the L/D to the pump from the combined suction is 400.7.

The head loss is calculated as follows:

$$h_L = 0.00259 \cdot 0.012 \cdot 311.4 \cdot \frac{(7600 \cdot 2)^2}{19.25^4} + 0.00259 \cdot 0.012 \cdot 400.7 \cdot \frac{7600^2}{19.25^4} + 9.5 \cdot \left(\frac{(7600 \cdot 2)}{68310.5} \right)^2$$
$$= 22.0\ ft$$

The resultant $NPSH_a$ would be 71.2 ft (93.2 ft – 22.0 ft).

- **Dual-Train Head Loss – Two Pumps Per Train**

For the shutdown cooling with two trains of RHR in operation and two pumps operating in each train (without RWCU flow), the NPSH margin is calculated based on a maximum of 14,600 gpm per train or 7300 gpm per pump (see Assumption 3).

Table 7 provides the take-off summary differentiating between the common suction and the separate loops. For conservatism, the branch connection where the flow separates is assumed to see the maximum flow. The L/D for the combined train suction is 311.4 and the L/D for the combined pump suction is 277.3 and the L/D to the pump from the combined pump suction is 123.4.

The head loss is calculated as follows:

$$h_L = 0.00259 \cdot \frac{0.012}{19.25^4} \cdot \left(311.4 \cdot (14600 \cdot 2)^2 + 277.3 \cdot (14600)^2 + 123.4 \cdot (7300)^2\right) + 9.5 \cdot \left(\frac{(14600 \cdot 2)}{68310.5} \right)^2$$
$$= 76.7\ ft$$

The resultant $NPSH_a$ would be 16.5 ft (93.2 ft – 76.7 ft).

It is noted that RWCU takes suction off the SDC header inside the drywell [5]. Adding this 130 gpm flow (see Assumption 9) into the combined train suction and vessel and recirculation loop flow yields a head loss of:

$$h_L = 0.00259 \cdot \frac{0.012}{19.25^4} \cdot \left(311.4 \cdot (14600 \cdot 2 + 130)^2 + 277.3 \cdot (14600)^2 + 123.4 \cdot (7300)^2\right) + 9.5 \cdot \left(\frac{(14600 \cdot 2 + 130)}{68310.5} \right)^2$$
$$= 77.2\ ft$$

The resultant $NPSH_a$ would be 16.0 ft (93.2 ft – 77.2 ft).

- **Dual-Train Head Loss – Two Pumps Per Train – Throttled Condition**

Based on the results to be presented, it will be noted that the above NPSHa is inadequate to maintain a positive NPSH margin to the RHR pumps. Therefore, a throttled condition will be examined that does provide adequate NPSH margin. It will be assumed that the throttled condition results in RHR pump flows of 6625 gpm per pump or 13,250 gpm per train and including RWCU flow.

The head loss is calculated as follows:

$$h_L = 0.00259 \cdot \frac{0.012}{19.25^4} \cdot \left(311.4 \cdot (13250 \cdot 2 + 130)^2 + 277.3 \cdot (13250)^2 + 123.4 \cdot (6625)^2\right) + 9.5 \cdot \left(\frac{(13250 \cdot 2 + 130)}{68310.5}\right)^2$$

$$= 63.7\ ft$$

The resultant $NPSH_a$ would be 29.5 ft (93.2 ft – 63.7 ft).

- **NPSH Margin**

The RHR pump required NPSH for unlimited operation at 7600 gpm is 33 ft, at 7400 gpm is 32 ft, at 7000 gpm is 29.5 ft and at 6400 gpm is 28.5 ft [VYC-0808 Rev. 6, Att. 3 pg. 5].

The minimum NPSH margin for each of the combinations analyzed above is summarized as follows:

Description	$NPSH_a$, ft	$NPSH_r$, ft	NPSH Margin, ft
SDC, One Train, One Pump	83.8.	33	50.8
SDC, Two Trains, One Pump per Train	71.2	33	38.2
SDC, Two Trains, Two Pumps per Train, max. flow	16.5	32	-15.5
SDC, Two Trains, Two Pumps per Train, max. flow w/ RWCU	16.0	32	-16.0
SDC, Two Trains, Two Pumps per Train, throttled w/ RWCU	29.5	29	0.5

Table 1 – From Recirc Loop "A" to RHR Pump "A" Suction

Reference	Length		Valves	Elbows		Tee		Misc	
	ft	in	Gate	90° SR	45° LR	Run	Branch	20-18 Red.	
Component L/D →			8	20	11	20	60		
5920-6637 Rev. 0 [10]		10.5	2	2			1		
		63							
		3.57							
G191210 Rev. 18 [18]	2	6		2					
& G191211 Rev. 16 [8]	10	3							
	8	7							
	5	5							
5920-9283 Rev. 4 [11]	5	6	1	1	2		1		
	2	8.5		3					
	3	6.5							
	2	1							
	2								
	2	11							
	8								
	3	8							
	9	2							
	1	6							
	9	4.5							
	6	7							
	5	1							
	2	9.5							
	14	7							
	4	3							
5920-9284 Rev. 3 [12]	8	6	1	2		1	1	2	
	1	6							
	7	2							
	2	6							
	3	4							
	9	6							
	2	7							
	3	5							
Total L/D →	85.4	11.5	32	200	22	20	180	2	552.9

Table 2 - From Recirc Loop "A" to RHR Pump "B" Suction

Reference	Length		Valves	Elbows		Tee		Misc	
	ft	in	Gate	90° SR	45° LR	Run	Branch	20-18 Red.	
Component L/D →			8	20	11	20	60		
5920-6637 Rev. 0 [10]		10.5	2	2			1		
		63							
		3.57							
G191210 Rev. 18 [18]	2	6		2					
& G191211 Rev. 16 [8]	10	3							
	8	7							
	5	5							
5920-9283 Rev. 4 [11]	5	6	1	1	2		1		
	2	8.5		3					
	3	6.5							
	2	1							
	2								
	2	11							
	8								
	3	8							
	9	2							
	4	2							
	2	9							
	4	7							
	2	7							
5920-9286 Rev. 4 [13]	19	3		4	1				
	5								
	1	3							
	7	1.5							
	1	4.5							
	3								
	3								
	7	6							
		1.5							
5920-9285 Rev. 4 [14]	4	3	1	2		2	1	2	
	3	10.5							
	4	6							
	11								
	3	4							
	9	6							
	3	8							
	2	10							
Total L/D →	98.5	12.1	32	280	33	40	180	2	677.6

Table 3 - From Recirc Loop "A" to RHR Pump "C" Suction

Reference	Length		Valves	Elbows		Tee		Misc	
	ft	in	Gate	90° SR	45° LR	Run	Branch	20-18 Red.	
Component L/D →			8	20	11	20	60		
5920-6637 Rev. 0 [10]		10.5	2	2			1		
		63							
		3.57							
G191210 Rev. 18 [18]	2	6		2					
& G191211 Rev. 16 [8]	10	3							
	8	7							
	5	5							
5920-9283 Rev. 4 [11]	5	6	1	1	2		1		
	2	8.5		3					
	3	6.5							
	2	1							
	2								
	2	11							
	8								
	3	8							
	9	2							
	1	6							
	9	4.5							
	6	7							
	5	1							
	2	9.5							
	14	7							
	4	3							
5920-9284 Rev. 3 [12]	8	6	1	2			2	2	
	5	10							
	3	5							
	9	6							
	1	10.5							
	2	9							
Total L/D →	81.0	11.7	32	200	22	0	240	2	588.8

Table 4 - From Recirc Loop "A" to RHR Pump "D" Suction

Reference	Length		Valves	Elbows		Tee		Misc	
	ft	in	Gate	90° SR	45° LR	Run	Branch	20-18 Red.	
Component L/D →			8	20	11	20	60		
5920-6637 Rev. 0 [10]		10.5	2	2			1		
		63							
		3.57							
G191210 Rev. 18 [18]	2	6		2					
& G191211 Rev. 16 [8]	10	3							
	8	7							
	5	5							
5920-9283 Rev. 4 [11]	5	6	1	1	2		1		
	2	8.5		3					
	3	6.5							
	2	1							
	2								
	2	11							
	8								
	3	8							
	9	2							
	4	2							
	2	9							
	4	7							
	2	7							
5920-9286 Rev. 4 [13]	19	3		4	1				
	5								
	1	3							
	7	1.5							
	1	4.5							
	3								
	3								
	7	6							
		1.5							
5920-9285 Rev. 4 [14]	4	3	1	2		1	2	2	
	3	10.5							
	4	6							
	6								
	3	4							
	9	1							
	1	8							
	1	4.5							
Total L/D →	93.5	11.6	32	280	33	20	240	2	712.1

Table 6 - From Recirc Loop "A" to RHR Pump "D" Suction

Reference	Length		Valves	Elbows		Tee		Misc	
	ft	in	Gate	90° SR	45° LR	Run	Branch	20-18 Red.	
Component L/D →			8	20	11	20	60		
5920-6637 Rev. 0 [10]		10.5	2	2			1		
		63							
		3.57							
G191210 Rev. 18 [18]	2	6		2					
& G191211 Rev. 16 [8]	10	3							
	8	7							
	5	5							
5920-9283 Rev. 4 [11]	5	6	1	1	2		1		
	2	8.5							
	3	6.5							
	2	1							
	2								
	2	11							
	8								
	3	8							
	9	2							
Full Flow L/D →	38.0	7.3	24	100	22	0	120	0	311.4
	4	2		3					
	2	9							
	4	7							
	2	7							
5920-9286 Rev. 4 [13]	19	3		4	1				
	5								
	1	3							
	7	1.5							
	1	4.5							
	3								
	3								
	7	6							
		1.5							
5920-9285 Rev. 4 [14]	4	3		1			1		
	3	10.5							
	4	6							
	6		1	1		1	1	2	
	3	4							
	9	1							
	1	8							
	1	4.5							
Half Flow L/D →	55.5	4.2	8	180	11	20	120	2	400.7

Table 7 - From Recirc Loop "A" to RHR Pump "D" Suction

Reference	Length		Valves	Elbows		Tee		Misc	
	ft	in	Gate	90° SR	45° LR	Run	Branch	20-18 Red.	
Component L/D →			8	20	11	20	60		
5920-6637 Rev. 0 [10]		10.5	2	2			1		
		63							
		3.57							
G191210 Rev. 18 [18]	2	6		2					
& G191211 Rev. 16 [8]	10	3							
	8	7							
	5	5							
5920-9283 Rev. 4 [11]	5	6	1	1	2		1		
	2	8.5							
	3	6.5							
	2	1							
	2								
	2	11							
	8								
	3	8							
	9	.2							
Full Flow L/D →	38.0	7.3	24	100	22	0	120	0	311.4
	4	2		3					
	2	9							
	4	7							
	2	7							
5920-9286 Rev. 4 [13]	19	3		4	1				
	5								
	1	3							
	7	1.5							
	1	4.5							
	3								
	3								
	7	6							
		1.5							
5920-9285 Rev. 4 [14]	4	3		1			1		
	3	10.5							
	4	6							
Half Flow L/D →	43.0	3.3	0	160	11	0	60	0	277.3
	6		1	1		1	1	2	
	3	4							
	9	1							
	1	8							
	1	4.5							
Quarter Flow L/D →	12.5	0.9	8	20	0	20	60	2	123.4

SULZER BINGHAM PUMPS INC.

QUALITY LEVEL	SULZER BINGHAM PUMPS INC. DOCUMENT	ASME CODE
☐ Direct	E12.5.561	SECTION
☐ Indirect	NPSH / MINIMUM FLOW STUDY - SUMMARY REPORT	CLASS NO.
	F-97-10782 (30P59)	CODE EDITION (YEAR)
		ADDENDA:
	SALES ORDER 270839/72 and 280418/9	SEASON
		YEAR

CUSTOMER: Yankee Atomic Electric Co. / Vermont Yankee

PROJECT: NPSH Study of RHR CS Pumps

CUSTOMER P.O. NO.: QA42125 — CHANGE ORDER NO. ______

SPECIFICATION NO.: N/A — REVISION NO. ______

CUSTOMER APPROVAL NUMBER

SPACE FOR CUSTOMER APPROVAL STAMP
(when applicable/available)

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CUSTOMER APPROVAL REQUIREMENT

☒ YES ☐ NO ☐ INFORMATION ONLY

CERTIFIED AS A VALID SULZER BINGHAM PUMPS INC. DOCUMENT

☒ For Outside Vendor
☐ For Manufacture at Sulzer Bingham Pumps Inc.
☐ Risk Release Inspection Report # ______
☐ Other (specify) ______

INITIAL APPROVALS (SIGNATURE)		Date
Engrg. Assurance	[signature]	5/26/98
Quality Assurance		

CERTIFICATION (when applicable)

This Document is certified to be in compliance with THE APPLICABLE PURCHASE ORDER, SPECIFICATIONS, PROCEDURES, AND ADDITIONAL REQUIREMENTS LISTED IN THE APPENDICES.

______
Professional Engineer

______ ______
State Registration No.

Date______ (Seal)

Originating Dept.: HQ Engineering

By: Rolf Lueneberg

Title: Hydraulic Design Consultant

Initial Date: 1 May, 1998

APPLICABLE S.O. NUMBERS

270839/842 and 280418/9

Control	Order Number	Rev.
		1

DOCUMENT IDENTIFICATION

Kenny/misc/f97-10782c

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Division of Sulzer Roteq

Status Sheet For: DOCUMENT REVISOIN RECORD

Revision No.	Issue Date	ECN No.	Location	Description	By/Approved
1	05-20-98	---	Page 3 Graphs	Item 3, Added Paragraph Revised graphs to E12.5.522 1B and 2B	KT / DZE 5/21/98

Initial Issue Date ________ Status Sheet Pg. ________ Cont. on Pg. ________ Doc. I.D. ________

Kenny/misc/docrevisionfrm.doc

SUBJECT: NPSH/Minimum Flow - Study (Summary Report)
Yankee Atomic Electric Company
Vermont Yankee
F97-10782
FS Reference - 30P59
Detailed Report - See E12.5.522

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ORIGINAL PERFORMANCE CURVE NO'S.:

I)	16 x 18 x 26 CVIC:	No. 28567	(S.O. No. 270839)
		27922	(S.O. No. 270840)
		28469	(S.O. No. 270841)
		28470	(S.O. No. 270842)

SERVICE: Residual Heat Removal (RHR)

II)	12 x 16 x 14½ CVDS:	No. 27691	(S.O. No. 280418)
		27692	(S.O. No. 280419)

SERVICE: Core Spray (CS)

I) Introduction

Purpose: To determine the pump operability requirements for (a) minimum pump flow and (b) minimum NPSH for the hypothetical design basis accident mode of operation. The minimum NPSH requirements are based on original pump test data and the application of SBPI knowledge and technology to supplement that data and to extend the range of the original data to higher and/or lower flow rates.

Note: This is a summary report of detailed NPSH report E12.5.522

II) Minimum Flow

A. Expected modes of operation under minimum flow conditions (defined by Vermont Yankee).

RHR - Pumps

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0 to ≤ 4 hours at 350 GPM
≥ 4 hours at 2700 GPM

CS - Pumps

0 to ≤ 4 hours at 300 GPM
≥ 4 hours at 1250 GPM

B. Vibration Data at Minimum Flow (supplied by Vermont Yankee).

Following vibration data were supplied to SBPI:

Data for pump and motor in table - form on 14 January 1998, for:
RHR - Pumps at 425 and 6500 GPM for
CS - Pumps at 300 and 3000 GPM

Additional vibration signatures for pump and motor on 18 March 1998, for CS - pumps at 300 GPM, to complete data from 14 January, 1998.

C. Evaluation of Vibration Data

RHR - Pumps

Data from 14 January 1998 are acceptable for the expected modes of operation under minimum flow conditions, although the overall vibration velocities (in/sec) peak readings were taken at a minimum flow of 425 GPM in lieu of 350 GPM.

CS - Pumps

Data from 14 January 1998 were not complete and indicated signs of unacceptability. Additional vibration signatures from 18 March 1998 are acceptable for the expected modes of operation under minimum flow conditions.

D. Basis for Minimum Flow Requirements

Continuous minimum flow is a function of pump specific speed "N_S", head per stage and suction specific speed N_{SS}-3% (at B.E.P.).

Lower minimum flows than continuous minimum flow are possible and acceptable for shorter durations of operation, depending on acceptable vibration levels (on pump and motor) and NPSH-Margin (NPSHA vs. NPSHR-3%).

For the expected modes of operation under minimum flow conditions:

RHR - Pumps

NPSHA from Vermont Yankee NPSHA-Curve. NPSHR-3% from SBPI Curve No. Id.

At 350 GPM
NPSHA = 35.8 Feet @ 155 °F, old strainer
NPSHR-3% = 30 Feet

At 2700 GPM
NPSHA = 34.5 Feet @ 155 °F, old strainer
NPSHR-3% = 26 Feet

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CS - Pumps

NPSHA from Vermont Yankee NPSHA-Curve. NPSHR-3% from SBPI Curve No. IId.

At 300 GPM
NPSHA = 36 Feet
NPSHR-3% = 32.5 Feet

At 1250 GPM
NPSHA = 35.5 Feet
NPSHR-3% = 27 Feet

E. Recommended Minimum Flow Requirements

The recommended minimum flow modes are the same as the expected modes of operations.

RHR - Pumps

0 to ≤ 4 hours at 350 GPM
≥ 4 hours at 2700 GPM

CS - Pumps

0 to ≤ 4 hours at 300 GPM
≥ 4 hours at 1250 GPM

III) NPSH

A. Expected modes of operation under minimum NPSH conditions (defined by Vermont Yankee).

Based on the operating conditions and the NPSHA per May-Witt Decay heat diagrams the expected modes are as follows:

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RHR - Pumps at 7000 GPM

7 hours with NPSHA of 23 to 24 ft.

Plus 5 additional hours with NPSHA of 24 to 26 ft.
Plus 5.5 additional hours with NPSHA of 26 to 28 ft.
Plus 3.5 additional hours with NPSHA of 28 to 29 ft.

CS - Pumps at 3000 GPM

7 hours with NPSHA of 24 to 25 ft.

Plus 2.5 additional hours with NPSHA of 25 to 26 ft.
Plus 2.5 additional hours with NPSHA of 26 to 27 ft.
Plus 3 additional hours with NPSHA of 27 to 28 ft.
Plus 6 additional hours with NPSHA of 28 to 30 ft.

B. Discuss pump performance based on original test data (included original data and curves)

The RHR - and CS - pumps have been NPSH-tested over a limited flow-range. No head-drop was specified on the original curves.

RHR-Pumps: B.E.P. - Flow at 6200 GPM

The most complete NPSH-Test was performed on Pump No. 270840 at maximum impeller diameter of 26.5 in.. NPSH-tests were performed at 6300, 8065 and 9502 GPM (See T-270840-A). 5 to 8 tests points were taken at each of the above capacities to establish the slope and shape of NPSH vs. Head. Purpose of the 'witness' tests were to demonstrate that the pump met the contractual requirements.

Witness - tests for each pump with a trimmed impeller diameter of 25.563 inch, only 2 to 3 NPSH - tests points were taken at capacities of approximately 6300, 7200, 8500 and 8900 GPM.

These tests are not complete enough to determine the exact NPSH-characteristics of the pumps. The duration of the witness - test of each pump, including flow from 0 to runout, pressures, head, RPM, efficiency, power and NPSH took between 1 and 2 hours.

This implies that the pumps were running only a few minutes with reduced NPSH. This is sufficient time to observe pump behavior at reduced NPSHA. In addition, no vibration readings were taken during these short duration NPSHA tests. A more thorough representation of the complete NPSHR characteristic is test T-270840-A. See SBPI Curve Ic. The difference in NPSHR due to impeller trim does not have a significant influence with these pumps.

<u>CS-Pumps:</u> B.E.P. - Flow at 3750 GPM

The most representative NPSH-Test was performed during Test No. 176101 at 13.81 inches and 13.00 inches impeller diameters. It was a pump for a different order, but an identical pump. NPSH - tests were performed at approximately 1780 RPM.

Converted to 3582 RPM, by using the affinity laws, the flow rates were 3005, 4037, 5038, 5120, 6000, 6020 and 6524 GPM (see T-176101-D/G). 4 to 10 tests points were taken at each of the above capabilities to establish the slope and shape of NPSH vs. Head. These tests are sufficient to develop NPSHR characteristics for the pump and are representative of the units delivered on the above serial numbers. Trim diameters have been factored in the developed NPSHR curves.

The most complete and representative test T-176101-D/G. (see also SBPI Curve No. IIc).

1. **Relationship to "Knee" of Pump Curve**

   When plotting the results of an NPSH-test (NPSH vs. Head), starting with ample NPSH, the head will either stay constant, vary or drop slightly with reducing NPSH. At some reduced NPSH value, the head will fall off more quickly before falling off totally. This defines the "Knee" of an NPSH-test.

   The knee may be very sharp, that means 1%, 3%, 6%, etc. head-drop will occur at about the same NPSHA value. Operation near or close to this type of knee is not recommended. The knee may also be well-rounded, that means 1%, 3%, 6% etc. head-drop will happen at different NPSHA values. To develop the shape of the NPSHR knee several test points are required.

2. **Similarity to Other Pumps Used in Nuclear Application**

   Pump designs provided for the above services are found in other nuclear installations in the same or similar applications. They are basically of similar style and design, but may differ in nozzle and maximum impeller sizes. There are pumps of same specific speed, suction specific speed and impeller inlet design features (NPSH).

3. **Relevant Operating Experience of Similar Pumps at Minimum NPSH**

   Operating conditions at various nuclear stations vary, however similar units to those furnished have been supplied to other installations with similar reduced NPSH levels during a nuclear incident. Similar reviews have been conducted for them.

Specified "normal" operating conditions (NPSHA) are not that close to NPSHR-3% or NPSHR-6%.

Operating for short durations at NPSHR-3% to NPSHR-6% should not be detrimental to the pump life in this service.

4. **Cavitation-Tests performed on same or similar pumps and conclusion from those tests.**

Cavitation (NPSH) - Tests have been performed on same pumps or similar pumps that have been used on the NPSH-study for Vermont Yankee.

NPSH-Test on same pumps is T-270840-A (RHR-Pump) and T-176101-D/G (CS-Pump) for discussion and conclusion see IIIB.

NPSH - Tests on similar pumps are used to establish tendencies and extrapolation of NPSH-Curves. (See SBPI Curve No. Id & IId). Similar pumps are of same suction specific speed, number of vanes and suction vane inlet angles.

5. **Acceptability of the units in their specified services.**

RHR - Pumps:

When operating for seven (7) hours at 7000 GPM with NPSHA of 23 to 24 feet, the pumps will be in the cavitation mode. The head-drop will be above 6% but the NPSHA is still greater than the original minimum operational NPSH (See SBPI Curve No. Ic and Id). The pumps, if operated with the minimum NPSH, are within acceptable limits of the NPSH "knee".

The pumps will remain acceptable following the "Postulated Accident Scenario" and operation under reduce NPSH conditions, providing NPSHA > NPSHR-3%.

CS - Pumps:

When operating for seven (7) hours at 3000 GPM with NPSHA of 24 to 25 feet, the pumps will be in the cavitation mode. The head-drop however will be less than 3% (see SBPI Curve No. IIc and IId). The pumps, if operated with the minimum NPSH limits, have adequate margin prior to the NPSH "knee".

The pumps will remain acceptable following the "Postulated Accident Scenario" and operation under minimum NPSH conditions, providing NPSHA > NPSHR-3%.

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C. Extrapolation to higher/lower flows using test date from other sources.

1. **Technical Basis for Extrapolation**

When pumps have been NPSH-tested for a small flow-range only (Vermont Yankee) and NPSH-data are required outside this flow-range, the NPSH-curves have to be extrapolated. Only NPSH-tests of pumps of similar style, design, specific speed, suction specific speed, impeller number of vanes and suction vane angles can be used for this purpose.

2. **Pump data selected and similarity to Vermont Yankee pumps**

RHR - Pumps:

Following pump sizes have been used to extend NPSHR to lower flows (see SBPI curve No. Ia):

18 x 24 x 28 CVIC
8 x 10 x 21 CVIC

CS - Pumps:

Following pump sizes have been used to extend NPSHR to lower flows (see SBPI curve No. IIa):

12 x 14 x 14 1/2 CVDS
14 x 16 x 23 CVDS

3. **Predicted NPSH at lower/higher flow rates as extrapolations of original test data**

In this case, the minimum flow rates are extremely low:

RHR-Pumps: 350 GPM $\hat{=} \frac{350}{6200} x 100 = 5.6\%$ of B.E.P. Flow

CS-Pumps: 300 GPM $\hat{=} \frac{300}{3750} x 100 = 8.0\%$ of B.E.P. Flow

No NPSH-tests of same or similar pumps are available at these low percentages of B.E.P. flow.

Extrapolation to these low flow rates based only on estimation and experience of NPSH-tests on other style of pumps. Experience comes from NPSH-tests which have been performed in recent years, when more detailed NPSH-tests were required.

Extrapolation for higher flow rate NPSHR is not necessary since sufficient test data exists for these flow rates. If extrapolation for higher flow rates is necessary a similar method will be used.

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D. Basis for Minimum NPSH Recommendations

1. No Permanent Pump Damage Due to Cavitation

Depending on water temperature and water chemistry there can be some 'frosting' (e.g. light pitting) on the impeller suction vanes, but there will be no detrimental pump damage due to cavitation when operating at minimum NPSH for the specified hours of operation.

This applies mainly to the RHR-pumps when operating for seven (7) hours at 7000 GPM with NPSHA of 23 to 24 feet. It will apply to a lesser degree to the CS-pumps when operating for seven (7) hours at 3000 GPM with NPSHA of 24 to 25 feet.

2. Operation above the "Knee" of the Pump Curve

Maintaining the minimum NPSH values is a "must" when operating near or at the NPSHR knee. For continuous operation this is essential, since small variances in product temperature can suddenly reduce the NPSHA. Provided the NPSH values are supplied for the RHR and CS services and durations, at these values limited, operation at the NPSHR "knees" are acceptable.

Short-Term Operation at the "Knee" is acceptable providing temperature is controlled.

3. Conformance to Original Pump Requirements and Extrapolated Requirements, as defined herein

These pumps meet the original NPSHR requirements as specified. The original pump NPSH requirements were not well defined. The result was only two (2) NPSH-Test points for each capacity were measured. From two (2) NPSH-test points it is not possible to establish the "knee". At each NPSH-test point (during witness tests) the pumps were operating only a few minutes and the capacity-range was limited. This was not considered critical since similar pumps of the same hydraulics had been comprehensively tested.

The extrapolated NPSH requirements apply mainly to a flow regime of 350 and 2700 GPM for the RHR-pumps and 300 and 1250 GPM for the CS-pumps as described under III.c.3. Due to unknown suction vane profile and clean-up on NPSH-margin as described under II.d is required.

E. **Recommended Minimum NPSH Requirements**

1. **Acceptable durations of operation:**

RHR-Pumps:

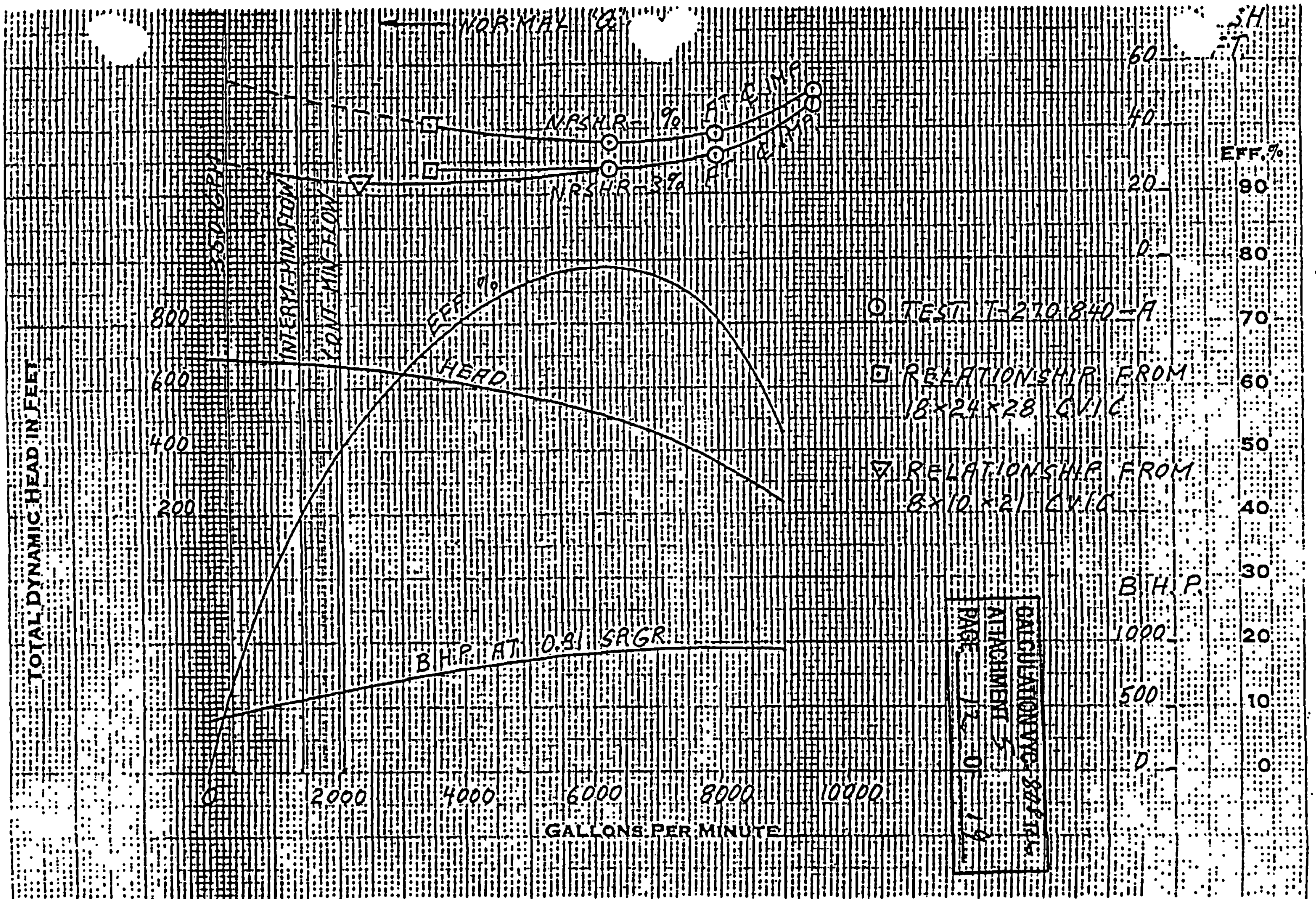
At minimum flow of 350 and 2700 GPM: as described under II.d and II.e.
At 7000 GPM: as shown on SBPI Curve No. E12.5.522-2B

CS-Pumps:

At minimum flow of 300 and 1250 GPM: as described under II.d and II.e.
At 3000 and 4600GPM: as shown on SBPI Curve No. E12.5.522-1B

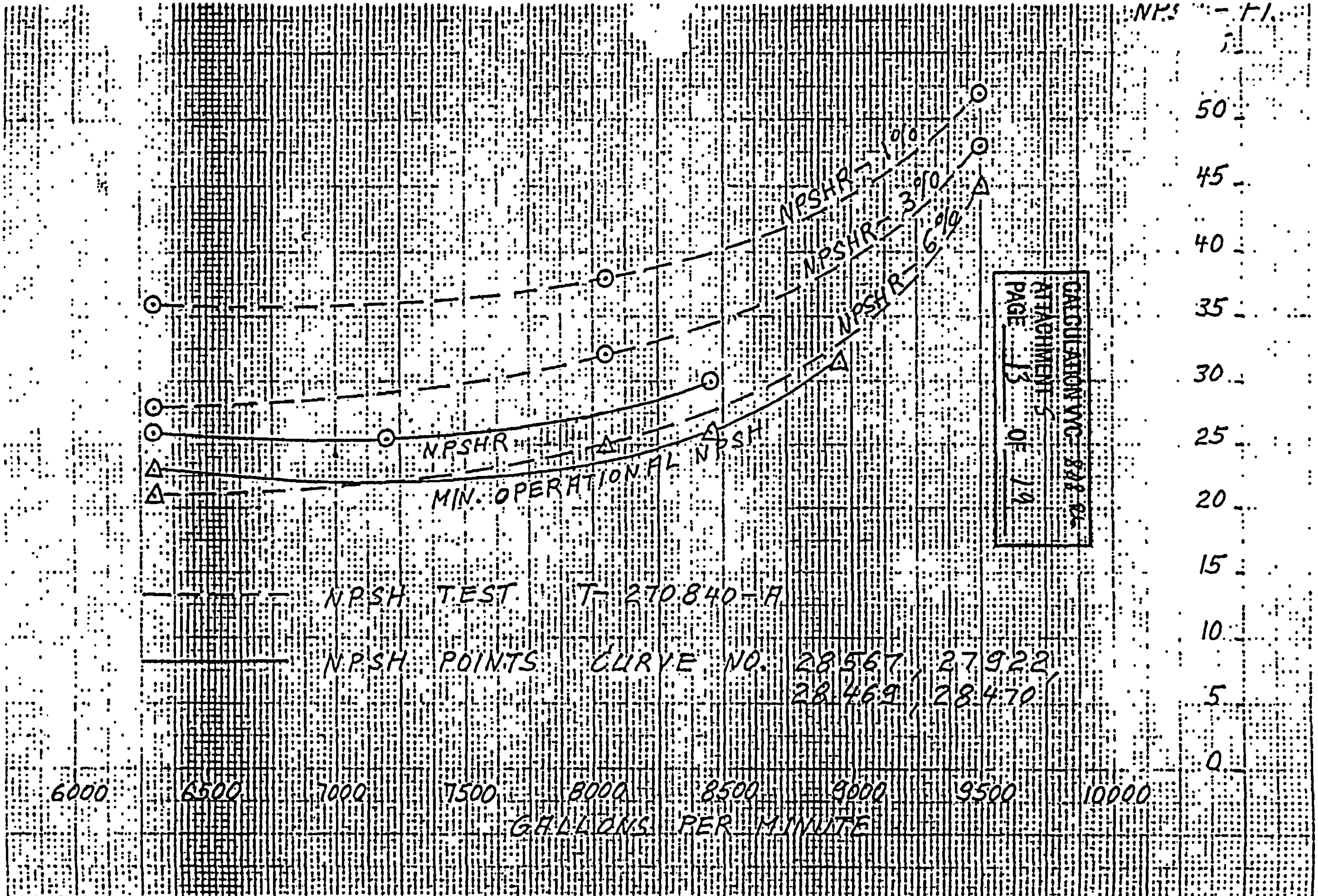
2. **Purpose of this report:**

This report and review was conducted to clarify test results taken approximately thirty (30) years earlier. It is also intended to provide additional understanding regarding the limits of these machines both hydraulically and mechanically. These machines are suitable for the services they were originally supplied to, however they must operated within the agreed limits.



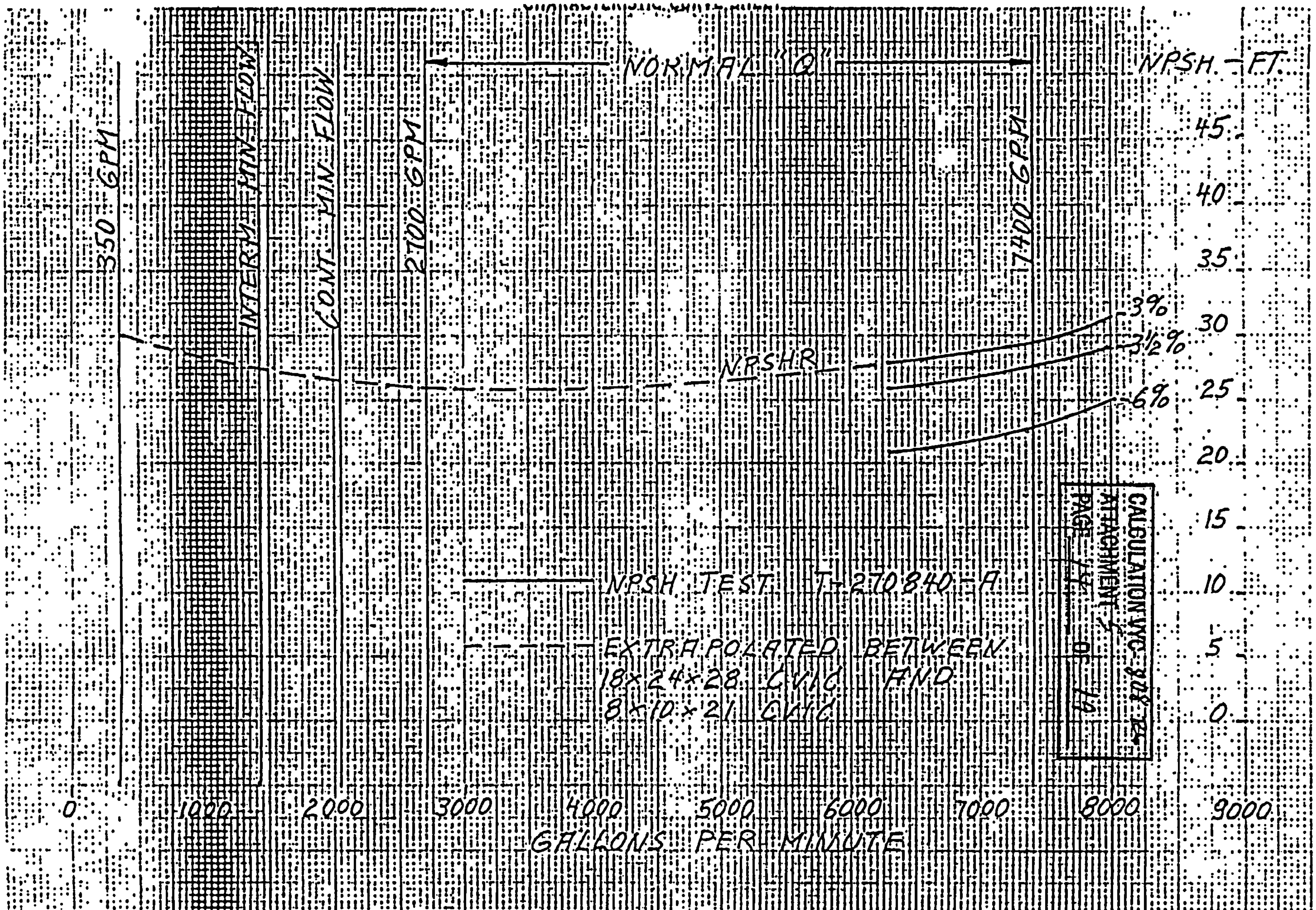
YANKEE ATOMIC ELECTRIC VERMONT YANKEE RHR PUMPS S.O. NO. 270839/842	PUMP ENGINEERING DEPT. **SULZER BINGHAM PUMPS INC.** 2. DEC. 97; R.L.	IMPELLER MAX. DIA. 26.500"	16 × 18 × 26 CVIC PUMP		
		MIN. DIA.	DIA. IMPELLER 25.563"	IMPELLER PATT. 1613 CVIC-1	1785 R.P.M.
		EYE AREA 121.3 SQ. IN.	N.P.S.H. REQUIRED	REFERENCE	CURVE No. Ia

Form No. 930-1



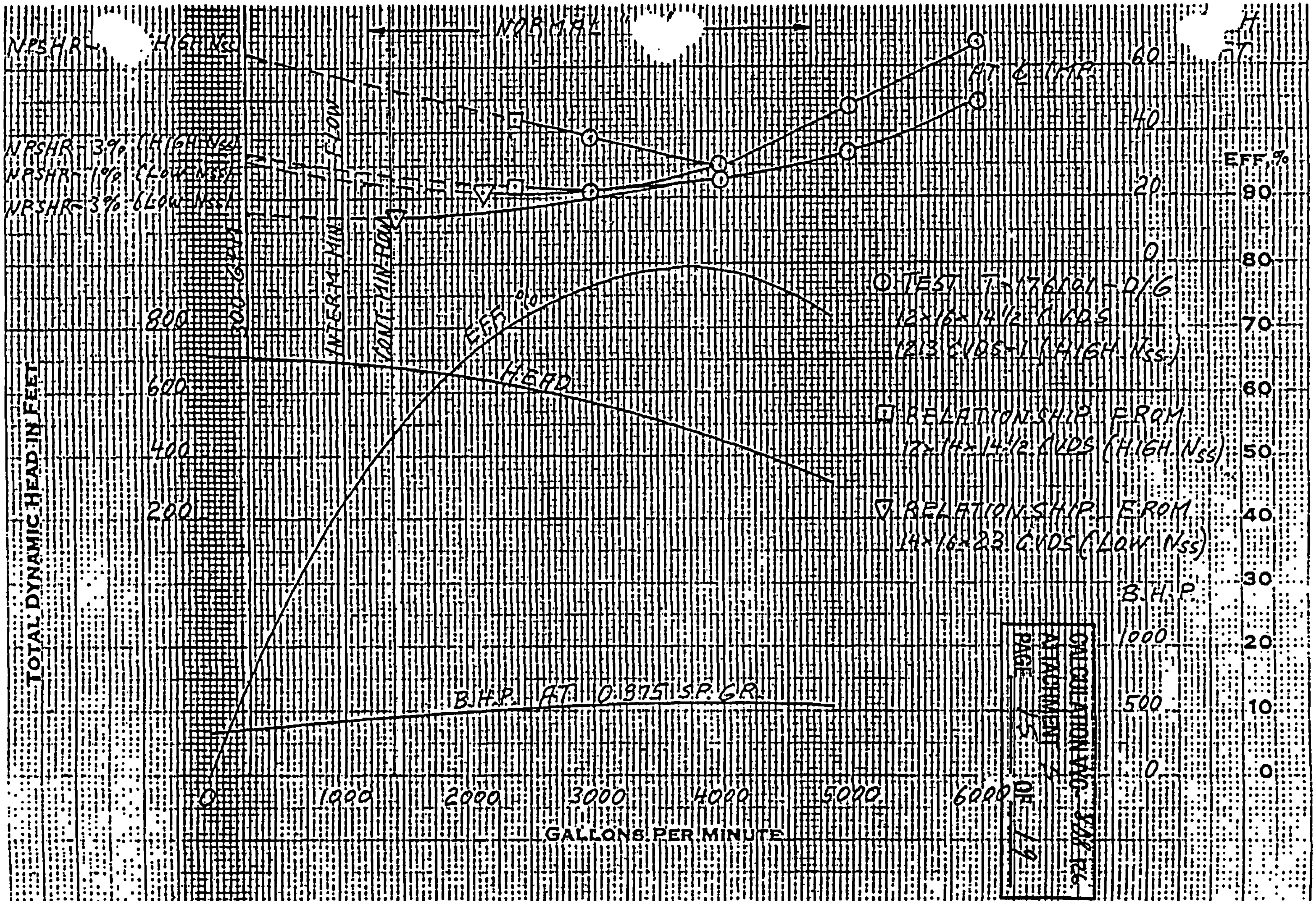
YANKEE ATOMIC ELECTRIC VERMONT YANKEE RHR PUMPS S.O. NO. 270 839/842	PUMP ENGINEERING DEPT. **SULZER BINGHAM PUMPS INC.** 18 MAR 98, R.L.	IMPELLER MAX. DIA. 26.500"	16×18×26 CVIC PUMP	
		MIN. DIA.	DIA. IMPELLER 25.563"	IMPELLER PATT. 1613 CVIC-1 / 1785 R.P.M.
		EYE AREA 121.3 SQ. IN.	N.P.S.H. REQUIRED	REFERENCE / CURVE No. I C

Form No. 308-2



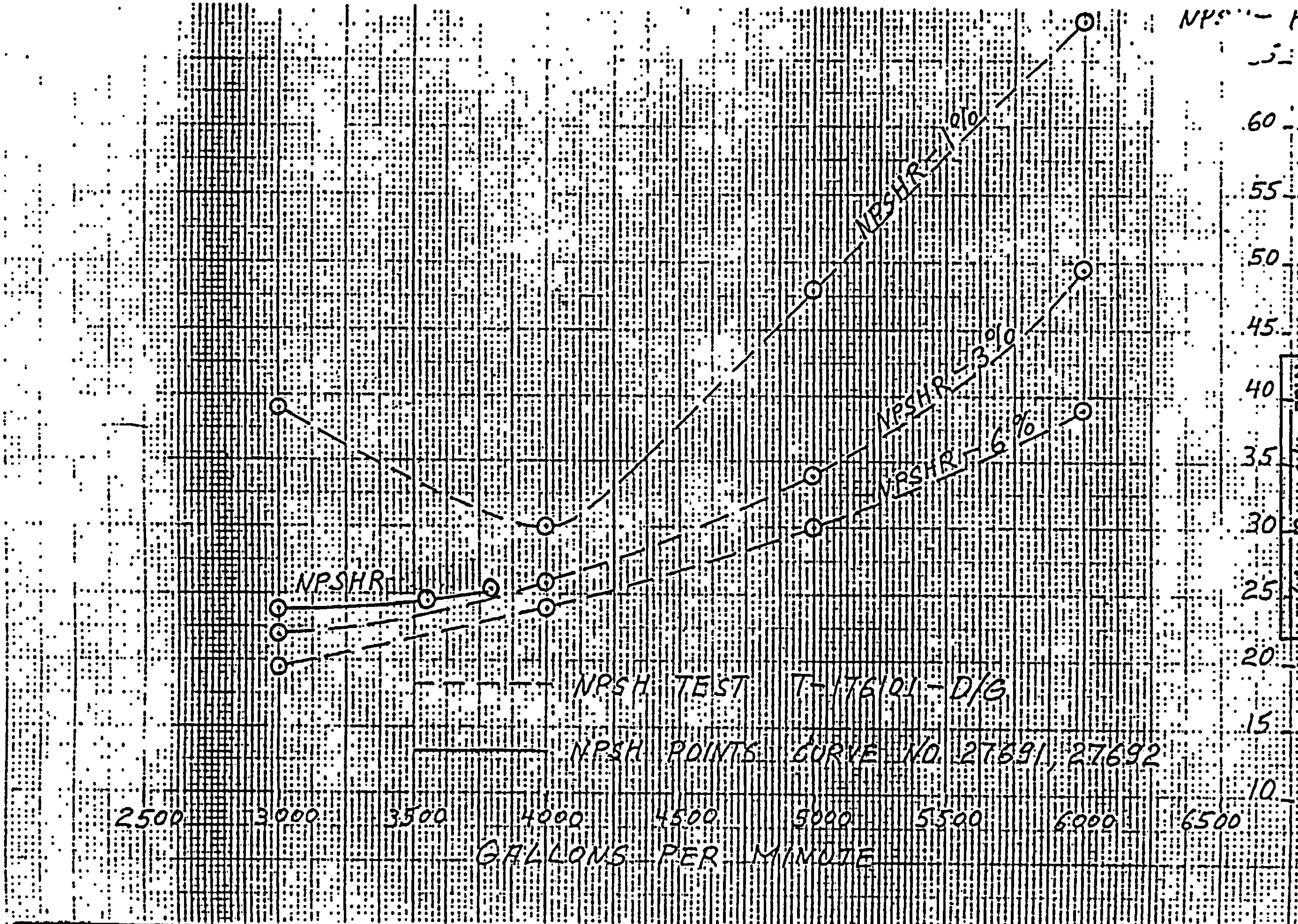
YANKEE ATOMIC ELECTRIC VERMONT YANKEE R.H.R. PUMPS S.O. NO. 270 839 / 842	PUMP ENGINEERING DEPT. **SULZER BINGHAM PUMPS INC.** 16. JAN. 98, R.L.	IMPELLER MAX. DIA. 26.500"	16×18×26 CVIC PUMP		
		MIN. DIA.	DIA. IMPELLER 25.563"	IMPELLER PATT. 1613 CVIC-1	1785 R.P.M.
		EYE AREA 121.3 SQ. IN.	N.P.S.H. REQUIRED	REFERENCE Ia, b, c	CURVE No. Id

Form No. 308-2



YANKEE ATOMIC ELECTRIC VERMONT YANKEE CS PUMPS S.O. NO. 280418/419	PUMP ENGINEERING DEPT. **SULZER BINGHAM PUMPS INC.** 4 DEC 97 ; R.L.	IMPELLER MAX. DIA. 14.500" MIN. DIA. EYE AREA 72.2 SQ. IN.	12×16×14 1/2 CVDS PUMP DIA. IMPELLER 12.500" / IMPELLER PATT. 1213 CVDS-1 / 3582 R.P.M. N.P.S.H. REQUIRED / REFERENCE / CURVE NO. IIa	

Form No. 930-1



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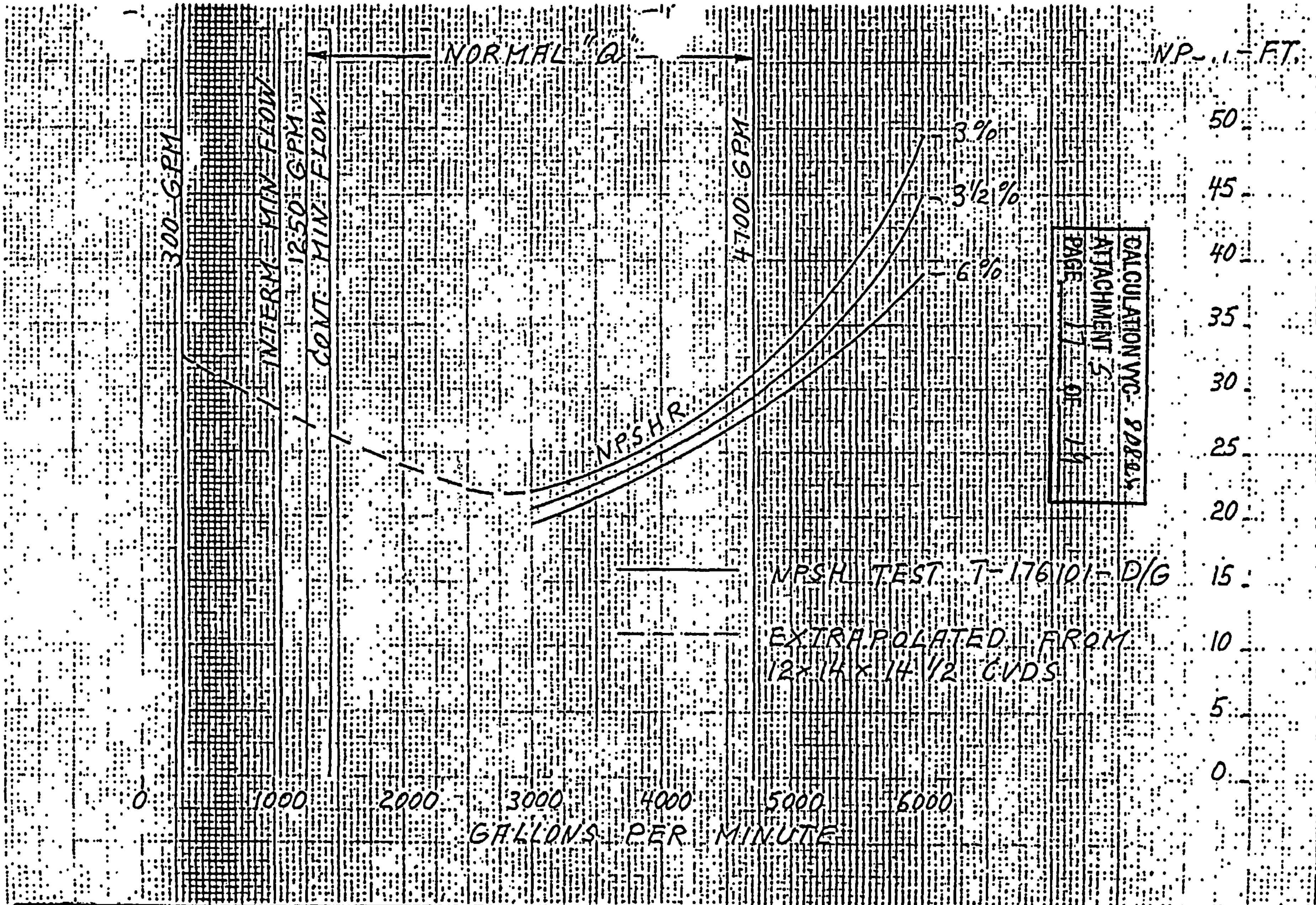
YANKEE ATOMIC ELECTRIC VERMONT YANKEE CS PUMPS S.O. NO. 280.418/419	PUMP ENGINEERING DEPT. **SULZER BINGHAM PUMPS INC.** 18 MAR 98; R.L.	IMPELLER MAX. DIA. 14.500" MIN. DIA. EYE AREA 72.2 SQ. IN.	12 × 16 × 14 1/2 CVDS PUMP	
			DIA. IMPELLER 12.500" N.P.S.H. REQUIRED	IMPELLER PATT. 1213 CVDS-1 REFERENCE
			3582 R.P.M. CURVE No. II c	

Form No. 309-2



YANKEE ATOMIC ELECTRIC VERMONT YANKEE C.S. PUMPS S.O. NO. 280 418/419	PUMP ENGINEERING DEPT. **SULZER BINGHAM PUMPS INC.** 16. JAN. 98 ; R.L.	IMPELLER MAX. DIA. 14.500" MIN. DIA. EYE AREA 72.2 SQ. IN.	12× 16 × 14½ CVDS PUMP DIA. IMPELLER 12.500" N.P.S.H. REQUIRED	IMPELLER PATT. 1213 CVDS-1 REFERENCE II a, b, c 3582 R.P.M. CURVE No. II d

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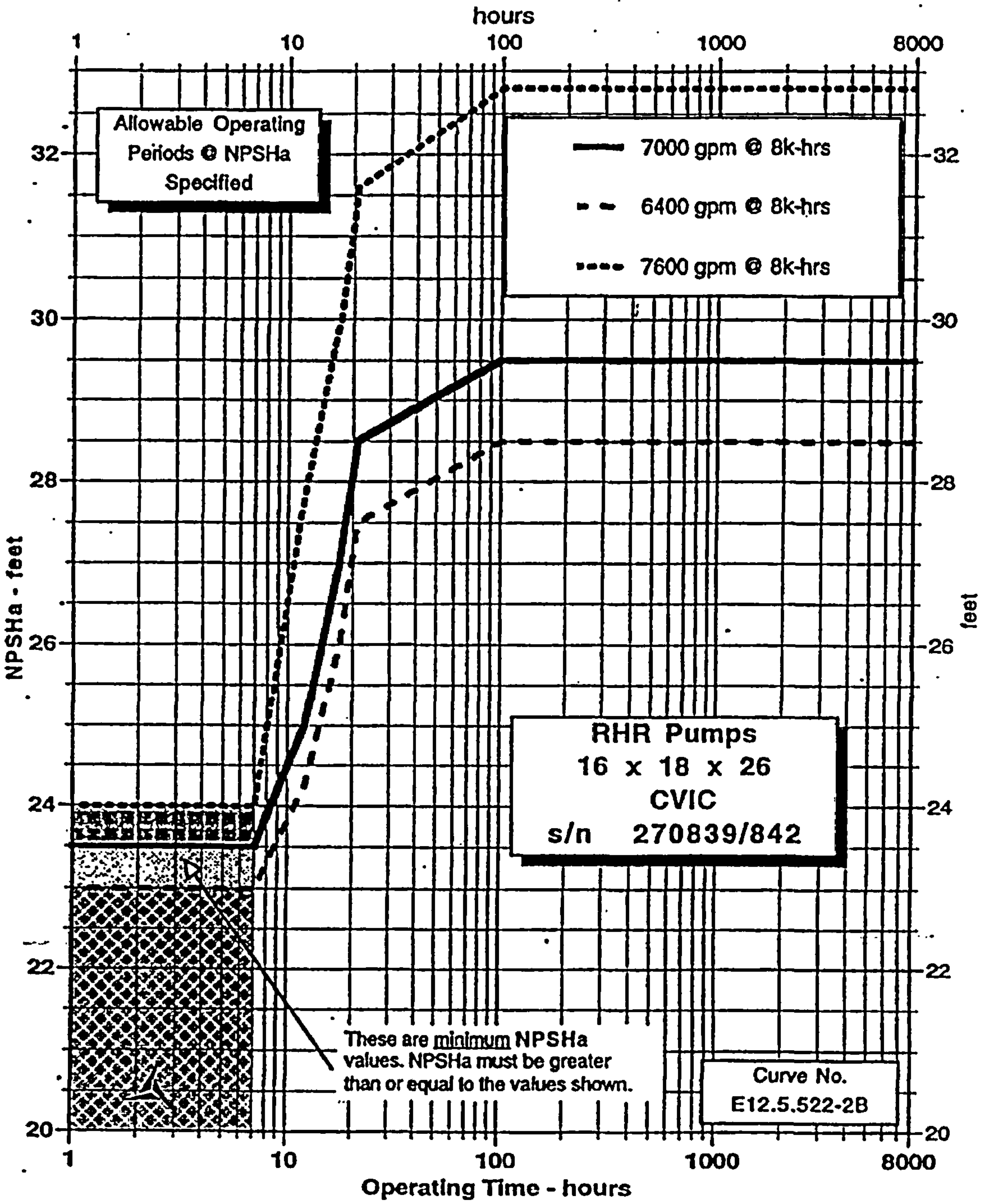

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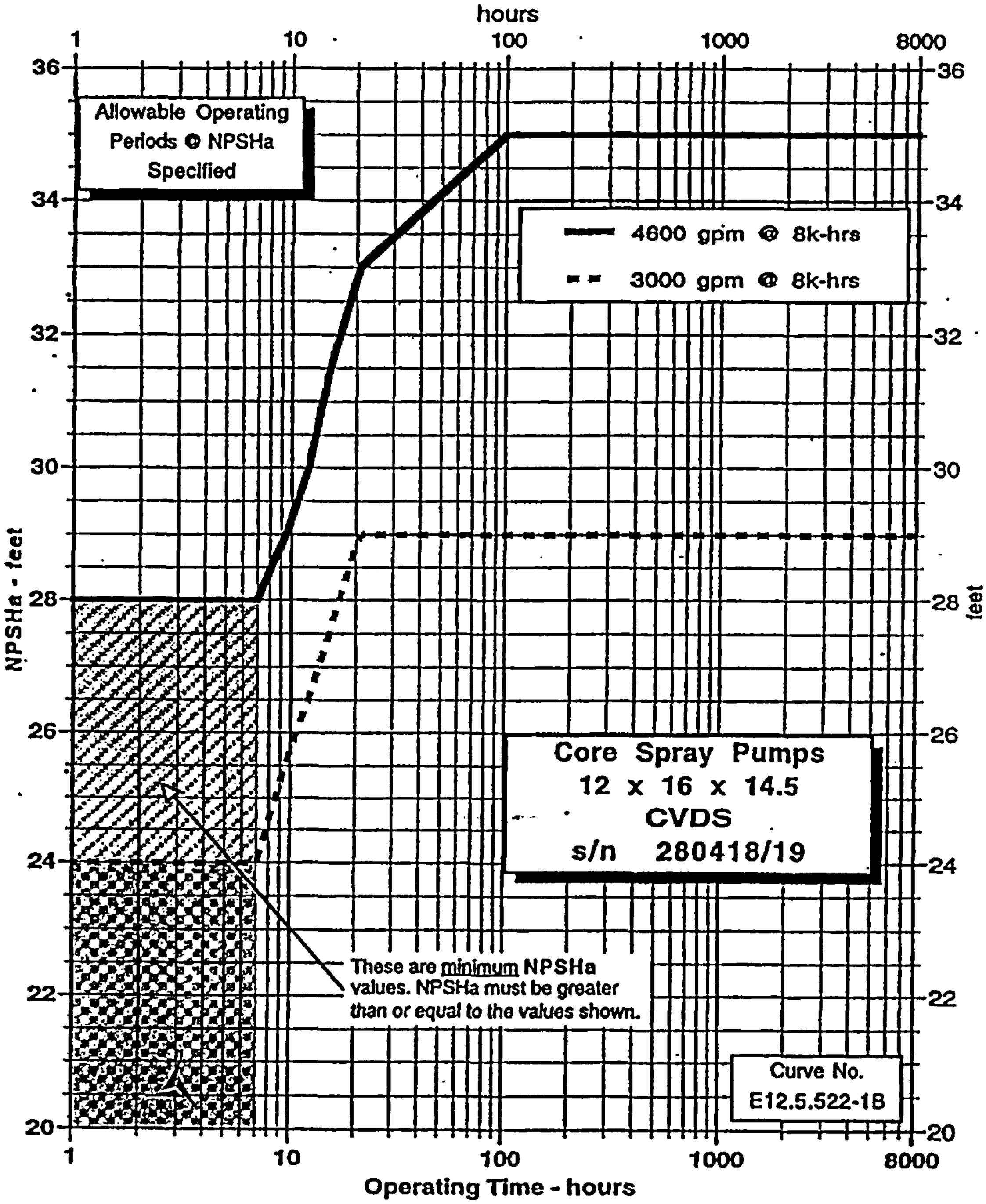

4 30P59VY.DG4 23:51 Tue May 19, 98

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SUBJECT Core Spray NPSH Evaluation

PREPARED BY ____ DATE ____ REVIEWED BY ____ DATE ____ WORK ORDER NO. 4922

5.0 References:

~~(a) Drawing, G-191168, Flow Diagram — Core Spray System~~ SHH · BES 4/25/00

(b) Drawing, 5920-9209, Core Spray (CS) Part 3

(c) Technical Paper No. 410, Flow of Fluids Through Valves Fittings and Pipe, Crane Co., 24th Printing, 1988

(d) Goulds Pump Manual, Gould Pumps Inc., Seneca Falls N.Y., 1973

(e) Pump Curve for Core Spray Pumps #280418, #280419, Bingham Pump Co., Curve Nos. 27691, 27692

(f) Drawing (CB & I), 6202-233, Torus Penetrations

(g) VYNPS FSAR, Fig. 5.2-1

(h) Drawing, G-191206, Core Spray System Piping Plan

(i) Drawing, G-191207, Core Spray System Piping Sections

(j) "Thermodynamic Properties of Steam", Keenan and Keyes, John Wiley and Sons, New York, 1959

(k) Drawing, 5920-6683, C.S. Suction Strainer for Torus Penetrations X-226A and X-226B

~~(l) Handbook of Hydraulic Resistance, I.E.Idelchik, 2nd Ed., Hemisphere Publishing Co., New York, 1986~~

(m) Hydraulic Institute Engineering Data Book, 1st Ed.

6.0 Calculation:

6.1 Suction Piping Lengths

Each Core Spray pump takes suction from its own Torus penetration. The two suction piping paths are essentially "mirror images".

6.1.1 Torus to CS Pump piping:

Pipe size = 12" STD [Ref.(a)]

Piping Lengths [Ref.(b)]

	Feet	Inches	
	3	0.0	
	3	2.5	
	3	1.5	
	1	9.0	
	7	6.0	
	4	3.0	
	0	3.5	
	1	0.5	
	1	6.0	
	2	4.0	
	3	6.0	
	2	5.0	
	0	11.5	
Total	30	58.5	or 34.875', say 35'

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SUBJECT Core Spray NPSH Evaluation

PREPARED BY ______ DATE ______ REVIEWED BY ______ DATE ______ WORK ORDER NO. 4922

6.1.2 Fittings [Ref. (b)]

	L/D		[Ref. (c)]
90° LR 16"x12" Red. Elbow	14	(Note 1)	
45° LR Elbow	11		[Ref. (m)]
67 1/2° LR Elbow	14	(Note 1)	
90° LR Elbow	14		
90° LR Elbow	14		
TEE (Str. Run)	20		
16"x12" Reducer (Exp.)	7		
Valve, Gate (CS-7A)	8		
~~Strainer Entrance Tee (16")~~	~~30~~		~~[Ref. (l)]~~
Total	~~132~~ 102		

Total equivalent length (12") pipe = 35 + ~~132~~ 102 = ~~167~~ 137

BCS 4/25/00

Note 1: Conservatively assumed same as 90° LR Elbow.

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6.1.3 Correction to Sched. 40 [Ref.(c)]

12" STD : I.D. = 12.00"

12" SCH 40 : I.D. = 11.938"

$dP_a = dP_{40} (D_{40}^5 / D_a^5)$ [Ref.(c), @ B-15]

Therefore,

$dP_{STD} = dP_{40} (11.938^5 / 12.00^5) = dP_{40} (0.974)$

Equivalent length Sched. 40:

$L_{40} = L_{STD} (0.974)$

= ~~(167)~~ 137 (0.974) = ~~162.63, say 163'~~ 133

6.2 Friction loss:

$H_f = (L)(h_f)$ [Ref.(c)]

@ 3000 gpm, h_f = 0.731 psi/100', (60 °F water)

$H_{f@3000}$ = (~~163~~ 133 ft.)(0.731 psi/100 ft.)(2.31 ft./psi) = ~~2.752~~ 2.25 ft.

For other flow rates:

$H_{f1} = H_{f0} (Q_1^2 / Q_0^2)$

Note: This is slightly conservative for $Q_1 > Q_0$, but difference is insignificant in the range of interest.

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SUBJECT Residual Heat Removal (LPCI) NPSH Evaluation

PREPARED BY ______ DATE ______ REVIEWED BY ______ DATE ______ WORK ORDER NO. 4922

5.0 References:

✓ (a) Drawing, G-191172, Flow Diagram - Residual Heat Removal System

✓ (b) Drawing, 5920-9284, Residual Heat Removal (RHR) Part 5

✓ (c) Technical Paper No. 410, Flow of Fluids Through Valves Fittings and Pipe, Crane Co., 24th Printing, 1988

(d) Goulds Pump Manual, Gould Pumps Inc., Seneca Falls N.Y., 1973

(e) Pump Curve for RHR Pump #270841, Bingham Pump Co., Curve No. 28469

(f) Drawing (CB & IO, 6202-233, Torus Penetrations

(g) VYNPS FSAR Fig. 5.2-1

(h) Drawing, G-191211, RHR System Piping Sections

(i) Drawing G-191210, RHR System Piping Plan

(j) "Thermodynamic Properties of Steam", Keenan and Keyes, John Wiley and Sons, New York, 1959

✓ (k) Handbook of Hydraulic Resistance, I.E.Idelchik, 2nd Ed., Hemisphere Publishing Co., New York, 1986

✓ (l) Hydraulic Institute Engineering Data Book, 1st Ed.

~~(m) Drawing 5920-6764, RHR Suction Strainer for Torus Penetrations X-224A & X-224B~~

6.0 Calculation:

6.1 Suction Piping Lengths

Two RHR pumps take suction from one Torus penetration therefore a portion of suction piping is common to both pumps from the Torus to a Tee at which point there is a single branch to each pump. Both the A and B RHR loops are mirror image so the calculation need be done for only one loop. (A and C pump loop.) By inspection of the piping isometric drawings it is noted that there are some small differences in the single suction lines the most significant of which is that one has a straight run at the Tee while the other is a branch run. The run with the greater loss will be used for conservative results.

6.1.1 Common piping Torus to Tee 24" pipe.

Pipe size = 24", 0.375 wall. I.D. = 23.25" (STD.) [Ref.(a)]

Piping Lengths [Ref.(b)]

	Feet	Inches		
	1	2.625		
	3	6.125		
	4	0.0		
Total	8	8.75	or	8.73 ft.

6.1.2 Fittings

	L/D		[Ref.(c)]
33° LR Elbow	7	(estimated)	
90° SR Elbow	20		
26"x24" Reducer (Exp.)	1		
~~Strainer Entrance Tee~~	~~119~~		~~[Ref.(h)]~~
~~24" 24° Mitre Bend~~	~~6~~		

Total ~~153~~ 28 or ~~296.44~~ 54.25 ft. equivalent

6.1.3 Correction to Sched. 40 (20")

24" STD : I.D. = 23.25"

20" SCH 40 : I.D. = 18.814"

$dP_a = dP_{40} (D_{40}{}^5 / D_a{}^5)$ [Ref.(c) @ B-15]

Therefore,

$dP_{STD} = dP_{40} (18.814^5 / 23.25^5) = dP_{40} (0.347)$

Equivalent length Sched. 40:

$L_{40} = L_{STD} (0.347)$ ✓

= (8.73 + ~~296.44~~ 54.25) (0.347) = ~~105.89'~~ 21.85'

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6.1.4 Common piping Torus to Tee 26" pipe.

Pipe size = 26", 0.375 wall. I.D. = 25.25" [Ref.(a)]

Piping Lengths [Ref.(b)]

	Feet	Inches		
	1	4.125		
	2	8.25		
	17	10.125		
	5	5.5		
	2	2.0		
	6	0.0		
	4	3.0		
	2	0.0		
	1	3.0		
Total	40	36	or	43.00 ft.

6.1.5 Fittings

	L/D		[Ref.(c)]
45° LR Elbow	11		[Ref.(1)]
45° LR Elbow	11		[Ref.(1)]
90° SR Elbow	20		
90° SR Elbow	20		
Total	62	or 130.46 ft. equivalent	

6.1.6 Correction to Sched. 40 (20")

26" STD : I.D. = 25.25"

20" SCH 40 : I.D. = 18.814"

$dP_a = dP_{40} (D_{40}{}^5 / D_a{}^5)$ [Ref.(c) @ B-15]

Therefore,

$dP_{STD} = dP_{40} (18.814^5 / 25.25^5) = dP_{40} (0.230)$

Equivalent length Sched. 40:

$L_{40} = L_{STD} (0.230)$

$= (43.00 + 130.46) (0.230) = 39.90'$

6.1.7 Total common piping 20" Sched. 40 equivalent

L_{COM} = ~~105.89~~ 21.85 + 39.90 = ~~145.79'~~ 61.75 (20", Sch. 40)

6.1.8 Single piping Tee to Pump A 26"

Pipe size = 26", 0.375 wall. I.D. = 25.25" [Ref.(a)]

Piping Lengths [Ref.(b)]

	Feet	Inches		
	3	10.0		
	2	5.5		
	2	3.5		
Total	7	19	or	8.58 ft.

6.1.9 Fittings

	L/D	
Tee (Str. Run)	20	
90° SR Elbow	20	
10° LR Elbow	1	(estimated)
26"x20" Reducer	17	
Total	58	or 122.04 ft. equivalent

6.1.10 Correction to Sched. 40 (20")

26" STD : I.D. = 25.25"

20" SCH 40 : I.D. = 18.814"

$dP_a = dP_{40} (D_{40}{}^5 / D_a{}^5)$ [Ref. (c) @ B-15]

Therefore,

$dP_{STD} = dP_{40} (18.814^5 / 25.25^5) = dP_{40} (0.230)$

Equivalent length Sched. 40:

$L_{40} = L_{STD} (0.230)$

$= (8.58 + 122.04) (0.230) = 30.04'$

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6.1.11 Single piping Tee to Pump A 20"

Pipe size = 20", 0.375 wall. I.D. = 19.25" [Ref.(a)]

Piping Lengths [Ref.(b)]

	Feet	Inches		
	1	8.0		
	3	7.0		
	3	5.0		
	2	11.0		
	2	7.0		
	3	5.0		
Total	14	43	or	17.58 ft.

6.1.12 Fittings

	L/D		[Ref.(c)]
90° SR Elbow	20		
Valve (10-13A),Gate	8		
90° SR Elbow	20		
Tee (20x20x20,Str. Run)	20		
Tee (20x4x20,Str. Run)	1		[Ref.(k)]
20"x18" Reducer	2	(estimated)	
Total	71	or 113.90 ft. equivalent	

6.1.13 Correction to Sched. 40 (20")

20" STD : I.D. = 19.25"

20" SCH 40 : I.D. = 18.814"

$dP_a = dP_{40} (D_{40}^{5} / D_a^{5})$ [Ref.(c) @ B-15].

Therefore,

$dP_{STD} = dP_{40} (18.814^{5} / 19.25^{5}) = dP_{40} (0.892)$

Equivalent length Sched. 40:

$L_{40} = L_{STD} (0.892)$

$= (17.58 + 113.90) (0.892) = 117.28'$

6.1.14 Total single piping Tee to Pump A 20" Sched. 40 equivalent

$L_{T-A} = 30.04 + 117.28 = 147.32'$

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6.1.15 Single piping Tee to Pump C 20"

Pipe size = 20", 0.375 wall. I.D. = 19.25" [Ref.(a)]

Piping Lengths [Ref.(b)]

Feet	Inches
2	3.5
0	9.5
2	10.0
3	4.0
3	4.0
3	0.0
1	10.5
2	9.0

Total 16 50.5 or 20.21 ft.

6.1.16 Fittings

	L/D		
			[Ref.(c)]
Tee (Br. Run)	60		
90° SR Elbow	20		
Valve (10-13C), Gate	8		
90° SR Elbow	20		
Tee (20x20x20, Str. Run)	20		
Tee (20x4x20, Str. Run)	1		[Ref.(k)]
20"x18" Reducer	2	(estimated)	
10° LR Elbow	1		

Total 132 or 211.75 ft. equivalent

6.1.17 Correction to Sched. 40 (20")

20" STD : I.D. = 19.25"

20" SCH 40 :I.D. = 18.814"

$dP_a = dP_{40} (D_{40}{}^5 / D_a{}^5)$ [Ref.(c) @ B-15]

Therefore,

$dP_{STD} = dP_{40} (18.814^5 / 19.25^5) = dP_{40} (0.892)$

Equivalent length Sched. 40:

$L_{40} = L_{STD} (0.892)$

$= (20.21 + 211.75) (0.892) = 206.91'$

6.1.18 Total single piping Tee to Pump C 20" Sched. 40 equivalent

$L_{T-C} = 206.91'$

6.1.19 Piping Summary - Equivalent Feet 20" Sched. 40

Torus to Tee (Common), (L_{COM}) = ~~145.79'~~ 61.75

Tee to Pump A, (L_{T-A}) = 147.32'

Tee to Pump C, (L_{T-C}) = 206.91'

Pump C has the longer run ; use for conservative result.

6.2 Friction Loss

$H_f = H_{f common} + H_{f\ single}$

Head loss in common line will depend on number of pumps operating. Assume that if both pumps are operating they are operating at the same flow rate.

Consider two configurations : One pump operation (Case I), and two pump operation (Case II).

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Case I Friction Loss :

$H_f = H_{f\ common} + H_{f\ single}$

and $H_{fa} = H_{fb}\ (\ Q_a^2\ /\ Q_b^2\ )$ [Ref.(c)]

as a function of flow where $Q_{common} = Q_{single}$ for Case I.

(Note: This is slightly conservative for $Q_a < Q_b$, but difference is not significant in range of interest.)

$H_{fI} = H_{fc0}\ (\ Q^2\ /\ Q_0^2\ ) + H_{fs0}\ (\ Q^2\ /\ Q_0^2\ )$

where H_{fc0} = friction loss at Q_0 for the common piping

and H_{fs0} = friction loss at Q_0 for the single piping

For Q_0 = 7000 gpm, friction loss for 20" Sched. 40 pipe is 0.376 psi per 100',

[Ref.(c)]

$H_{fc0} = L_{COM}\ (H_{f0})$

= (~~445.38~~ 61.75) (0.376 / 100) (2.31 ft/psi) = ~~1.266'~~ 0.536'

$H_{fs0} = L_{T-C}\ (H_{f0})$

= (206.91) (0.376 / 100) (2.31 ft/psi) = 1.80'

$H_{f0I} = H_{fc0} + H_{fs0}$ = ~~1.266~~ 0.536 + 1.80 = ~~3.066'~~ 2.336 @ 7000gpm

therefore,

H_{fI} = ~~3.066~~ 2.336 (Q^2 / 7000^2) = ~~6.26~~ 4.77 $\times 10^{-8}\ Q^2$

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Case II Friction Loss :

$H_f = H_f$ common $+ H_f$ single

and $H_{fa} = H_{fb} (Q_a^2 / Q_b^2)$ [Ref.(c)]

as a function of flow where $Q_{common} = 2\, Q_{single}$ for Case II.

$H_{fII} = H_{fc0} (Q^2 / Q_0^2) + H_{fs0} (Q^2 / Q_0^2)$

where H_{fc0} = friction loss at Q_0 for the common piping

and H_{fs0} = friction loss at Q_0 for the single piping

For Q_0 = 7000 gpm (one pump flow), friction loss for 20" Sched. 40 pipe is 0.376 psi per 100' [Ref.(c)]

For Q_0 = 14000 gpm (two pump flow), friction loss for 20" Sched. 40 pipe is 1.43 psi per 100' [Ref.(c)]

$H_{fc0} = L_{COM} (H_{f0})$

= (~~145.79~~ 61.75) (1.43 / 100) (2.31 ft/psi) = ~~4.816'~~ 2.040 ~~2.039~~

$H_{fs0} = L_{T-C} (H_{f0})$

= (206.91) (0.376 / 100) (2.31 ft/psi) = 1.80'

$H_{foII} = H_{fc0} + H_{fs0}$ = ~~4.816~~ 2.04 + 1.80 = ~~6.616'~~ 3.84 @ 7000gpm per pump

therefore,

H_{fII} = ~~4.816~~ 2.04 ($Q_C^2 / 14000^2$) + 1.80 ($Q_S^2 / 7000^2$)

and for $Q_C = 2Q_S$

H_{fII} = ~~4.816~~ 2.04 (($2Q_S$)^2 / 14000^2) + 1.80 ($Q_S^2 / 7000^2$)

= ~~9.828×10^{-8}~~ 4.163×10^{-9} Q^2 + $3.673 \times 10^{-8}\, Q^2$ = ~~1.350×10^{-7}~~ 7.836×10^{-8} Q^2

Excel Verification Sample Calculation

Table 4.1 CS Verification (Line 40):

Cell G40 = $F$30
= 12.47

Cell H40 = 0.00000025*$F$9^2
= 0.00000025*4600^2
= 5.29

Cell I40 = $F$17
= 0.51

Cell J40 = ROUND(IF(C40<173,0.32*(173/C40),0.32),2)
= 165.1<173 = True
= 0.32*(173/C40)
= 0.32*(173/165.1)
= 0.34

Cell K40 =+((14.7-E40)*144*F40)+G40-H40-I40-J40
= ((14.7-5.349)*144*0.016423)+12.47-5.29-0.51-0.34
= 28.44

Cell L40 = $F$33
= 28.00

Cell M40 =IF((+L40-K40)/(144*F40)>0,(+L40-K40)/(144*F40),0)
=(28.00-28.44)/(144*0.016423) = -0.186<0, False
= 0

Cell N40 = +D40-14.7
= 17.64-14.7
= 2.94

Table 4.2 CS Table Verification (Line 50):

Cell F50 = $F$25
= 12.57

Cell G50 = 0.00000025*$F$9^2
= 0.00000025*3500^2
= 3.06

Cell H50 = 0.38*(($F$9/4000)^2)
= 0.38*((3500/4000)^2)
= 0.29

Cell I50 = ROUND(IF(B50<173,$F$18*(173/B50),$F$18),2)
194.3<173 = False (For True outcome see below, Cell I72)
= $F$18
= 0.21

Cell I72 = ROUND(IF(B72<173,$F$18*(173/B72),$F$18),2)
= 162.9<173 = True
= $F$18*(173/B72)
= 0.21*(173/162.9)
= 0.22

Cell J50 = +((14.7-D50)*144*E50)+F50-G50-H50-I50
= ((14.7-10.233)*144*0.016599)+12.57-3.06-0.29-0.21
= 19.687 [Worksheet shows 19.68 - Check OK - difference attributed to significant figures used in hand calc vs Excel]

Cell K50 = $F$28
= 29.6

Cell L50 = IF((+K50-J50)/(144*E50)>0,(+K50-J50)/(144*E50),0)
(29.6-19.68)/(144*0.016599) = 4.15>0 True (For False outcome see below, Cell L34)
= 4.15

Cell L34 = IF((+K34-J34)/(144*E34)>0,(+K34-J34)/(144*E34),0)
= (29.6-29.73)/(144*0.016449) = -0.055>0 False
= 0

Cell M50 = +C50-14.7
= 22.42-14.7
= 7.72

Table 4.2 RHR Table Verification (Line 78):

Cell F78 = $C$25
= 12.40

Cell G78 = 0.0000000477*$C$9^2
= 0.0000000477*7400^2
= 2.61

Cell H78 = $C$15
= 0.33

Cell I78 = ROUND(IF(B78<173,$C$18*(173/B78),$C$18),2)
169.7<173 = True (For False outcome see below, Cell I81)
= $C$18*(173/B78)
= 0.33*(173/169.7)
= 0.34

Cell I81 = ROUND(IF(B81<173,$C$18*(173/B81),$C$18),2)
180<173 = False
= $C$18
= 0.33

Cell J78 = +((14.7-D78)*144*E78)+F78-G78-H78-I78
= ((14.7-5.951)*144*0.016449)+12.40-2.61-0.33-0.34
= 29.84

Cell K78 = $C$28
= 31.7

Cell L78 = IF((+K78-J78)/(144*E78)>0,(+K78-J78)/(144*E78),0)
(31.7-29.84)/(144*0.016449)=0.785>0 True (For False outcome see below, Cell L116)
= 0.785 [Worksheet shows 0.78 - Check OK - difference attributed to significant figures used in hand calc vs Excel]

Cell L116 = IF((+K116-J116)/(144*E116)>0,(+K116-J116)/(144*E116),0)
= (31.7-31.84)/(144*0.016411) = -0.059>0 False
= 0

Cell M78 = +C78-14.7
= 17.71-14.7
= 3.01

Excel Verification

	A	B	C	D	E	F
1	**LOCA - Short Term**					
2	NPSHa =	(14.7-Pg)(144/Vf)+Z-hf-hs-hd				
3	OPR =	(NPSHr - NPSHa)/(144*Vf)				
4	OPA =	Over pressure available				
5	OPC =	Over pressure credited				
6						
7						
8	Short Term Flow Rate (gpm)					
9	1 RHR		Q = 7400	CS		Q = 4600
10	2 RHR		Q = 14800			
11						
12	Suction Line Losses (ft)					
13	1 RHR		hf = 4.77E-8*Q^2	CS		hf = 2.5E-7*Q^2
14	2 RHR		hf = 7.84E-8*(Q/2)^2			
15						
16	Clean Strainer Losses (ft)					
17	1 RHR		hs = 0.33	CS		hs = 0.81
18	2 RHR		hs = 1.22			
19						
20	Maximum Debris Losses (ft) @ ≥ base temperature					
21	1 RHR		hd = 0.33@173F	CS		hd = 0.32@173F
22	2 RHR		hd = 0.48@170F			
23						
24	Maximum Debris Losses (ft) @ < base temperature					
25	1 RHR		hd = .33*(173/T)	CS		hd = .32*(173/T)
26	2 RHR		hd = .48*(170/T)			
27	where T = suppression pool temperature, F					
28						
29	Elevation Head (ft)					
30	RHR		Z = 12.3	CS		Z = 12.47
31						
32	NPSHr (ft)					
33	1 RHR		NPSHr = 23.8	CS		NPSHr = 26
34	2 RHR		NPSHr = 23.6			
35						

36 Short Term (After EPU) - Peak Torus Temperature - 1.5 wt. % Containment Leakage & 100% Spray Efficiency

Row	Pump(s)	Time (sec)	GE Pool Temp (F)	GE Pool Pressure psia	Pg (psia)	Vf (ft^3/lb)	Z (ft)	hf (ft)	hs (ft)	hd (ft)	NPSHa (ft)	NPSHr (ft)	OPR (psig)	OPA (psig)	OPC (psig)
40	CS	600	165.1	17.64	6.349	0.016423	=$F$30	=0.000000025*$F$9^2	=$F$17	=ROUND(IF(C40<173,0.32*(173/C40),0.32),2)	=+((14.7-E40)*144*F40)+G40-H40-I40-J40	=$F$33	=IF(((L40-K40)/(144*F40))>0,(L40-K40)/(144*F40),0)	=+D40-14.7	0
41	1 RHR	600	165.1	17.64	6.349	0.016423	=$C$30	=0.0000000477*$C$9^2	=$C$17	=ROUND(IF(C41<173,0.33*(173/C41),0.33),2)	=+((14.7-E41)*144*F41)+G41-H41-I41-J41	=$C$33	=IF(((L41-K41)/(144*F41))>0,(L41-K41)/(144*F41),0)	=+D41-14.7	0
42	2 RHR	600	165.1	17.64	6.349	0.016423	=$C$30	=0.0000000784*($C$10/2)^2	=$C$18	=ROUND(IF(C42<170,0.48*(170/C42),0.48),2)	=+((14.7-E42)*144*F42)+G42-H42-I42-J42	=$C$34	=IF(((L42-K42)/(144*F42))>0,(L42-K42)/(144*F42),0)	=+D42-14.7	0

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	**LOCA - Long Term**													
2	NPSHa =	(14.7-Pg)(144Vf)+Z-hf-hs-hd												
3	OPR =	Over pressure required (NPSHr - NPSHa)(144*Vf)												
4	OPA =	Over pressure available												
5	OPC =	Over pressure credited												
8	Long Term Flow Rate (gpm)													
9		1 RHR	Q= 7400		CS		Q= 3000							
11	Suction Line Losses (ft)													
12		1 RHR	hf= 4.77E-8*Q^2		CS		hf= 2.5E-7*Q^2							
14	Clean Strainer Losses (ft)													
15		1 RHR	hs= 0.33		CS		hs= .38*(Q/4000)^2							
16							for Q<= 4000							
17	Maximum Debris Losses (ft) @ >= 173F													
18		1 RHR	hd= 0.33		CS		hd= 0.21							
20	Maximum Debris Losses (ft) @ < 173F													
21		1 RHR	hd= .33*(173/T)		CS		hd= .21*(173/T)							
22	where T = suppression pool temperature, F													
24	Elevation Head (ft)													
25		RHR	Z= 12.4		CS		Z= 12.57							
27	NPSHr (ft)													
28		1 RHR	NPSHr= 31.7		CS		NPSHr= 28.6							
30	**CS - Long Term (After EPU) 1.8 wt. % Containment Leakage & 100% Spray Efficiency**													
31-33	Time (sec)	OS Pool Temp (F)	OS Pool Pressure psia	Pg (psia)	Vf (ft^3/lb)	Z (ft)	hf (ft)	hs (ft)	hd (ft)	CS NPSHa (ft)	CS NPSHr (ft)	CS OPR (psig)	OPA (psig)	OPC (psig)
34	785.6745	168.7	17.71	6.851	0.016446	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B34<173,$F$18*(173/B34),$F$18),2)	=((14.7-D34)*144*E34)+F34-G34-H34-I34	=$F$28	=IF((K34-J34)/(144*E34)>0,(K34-J34)/(144*E34),0)	=C34-14.7	=VLOOKUP(A34,$G$122:$K$153,2)
35	1087.895	171.8	17.94	6.245	0.016461	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B35<173,$F$18*(173/B35),$F$18),2)	=((14.7-D35)*144*E35)+F35-G35-H35-I35	=$F$28	=IF((K35-J35)/(144*E35)>0,(K35-J35)/(144*E35),0)	=C35-14.7	=VLOOKUP(A35,$G$122:$K$153,2)
36	2033.365	176.6	18.87	6.962	0.016489	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B36<173,$F$18*(173/B36),$F$18),2)	=((14.7-D36)*144*E36)+F36-G36-H36-I36	=$F$28	=IF((K36-J36)/(144*E36)>0,(K36-J36)/(144*E36),0)	=C36-14.7	=VLOOKUP(A36,$G$122:$K$153,2)
37	2982.373	180	19.17	7.511	0.016509	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B37<173,$F$18*(173/B37),$F$18),2)	=((14.7-D37)*144*E37)+F37-G37-H37-I37	=$F$28	=IF((K37-J37)/(144*E37)>0,(K37-J37)/(144*E37),0)	=C37-14.7	=VLOOKUP(A37,$G$122:$K$154,2)
38	4186.48	183.4	19.9	8.096	0.01653	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B38<173,$F$18*(173/B38),$F$18),2)	=((14.7-D38)*144*E38)+F38-G38-H38-I38	=$F$28	=IF((K38-J38)/(144*E38)>0,(K38-J38)/(144*E38),0)	=C38-14.7	=VLOOKUP(A38,$G$122:$K$153,2)
39	5125.042	185.2	20.34	8.42	0.016541	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B39<173,$F$18*(173/B39),$F$18),2)	=((14.7-D39)*144*E39)+F39-G39-H39-I39	=$F$28	=IF((K39-J39)/(144*E39)>0,(K39-J39)/(144*E39),0)	=C39-14.7	=VLOOKUP(A39,$G$122:$K$153,2)
40	6275.292	187	20.82	8.756	0.016552	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B40<173,$F$18*(173/B40),$F$18),2)	=((14.7-D40)*144*E40)+F40-G40-H40-I40	=$F$28	=IF((K40-J40)/(144*E40)>0,(K40-J40)/(144*E40),0)	=C40-14.7	=VLOOKUP(A40,$G$122:$K$153,2)
41	8035.636	189.1	21.5	9.161	0.016564	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B41<173,$F$18*(173/B41),$F$18),2)	=((14.7-D41)*144*E41)+F41-G41-H41-I41	=$F$28	=IF((K41-J41)/(144*E41)>0,(K41-J41)/(144*E41),0)	=C41-14.7	=VLOOKUP(A41,$G$122:$K$153,2)
42	10219.89	191	21.86	9.541	0.016576	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B42<173,$F$18*(173/B42),$F$18),2)	=((14.7-D42)*144*E42)+F42-G42-H42-I42	=$F$28	=IF((K42-J42)/(144*E42)>0,(K42-J42)/(144*E42),0)	=C42-14.7	=VLOOKUP(A42,$G$122:$K$153,2)
43	12083.67	192.3	22.06	9.796	0.016585	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B43<173,$F$18*(173/B43),$F$18),2)	=((14.7-D43)*144*E43)+F43-G43-H43-I43	=$F$28	=IF((K43-J43)/(144*E43)>0,(K43-J43)/(144*E43),0)	=C43-14.7	=VLOOKUP(A43,$G$122:$K$153,2)
44	15169.8	193.6	22.31	10.063	0.016594	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B44<173,$F$18*(173/B44),$F$18),2)	=((14.7-D44)*144*E44)+F44-G44-H44-I44	=$F$28	=IF((K44-J44)/(144*E44)>0,(K44-J44)/(144*E44),0)	=C44-14.7	=VLOOKUP(A44,$G$122:$K$153,2)
45	17069.2	194.3	22.43	10.233	0.016599	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B45<173,$F$18*(173/B45),$F$18),2)	=((14.7-D45)*144*E45)+F45-G45-H45-I45	=$F$28	=IF((K45-J45)/(144*E45)>0,(K45-J45)/(144*E45),0)	=C45-14.7	=VLOOKUP(A45,$G$122:$K$153,2)
46	20156.38	194.6	22.46	10.298	0.016601	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B46<173,$F$18*(173/B46),$F$18),2)	=((14.7-D46)*144*E46)+F46-G46-H46-I46	=$F$28	=IF((K46-J46)/(144*E46)>0,(K46-J46)/(144*E46),0)	=C46-14.7	=VLOOKUP(A46,$G$122:$K$153,2)
47	23811.7	194.7	22.48	10.32	0.016601	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B47<173,$F$18*(173/B47),$F$18),2)	=((14.7-D47)*144*E47)+F47-G47-H47-I47	=$F$28	=IF((K47-J47)/(144*E47)>0,(K47-J47)/(144*E47),0)	=C47-14.7	=VLOOKUP(A47,$G$122:$K$153,2)
48	24494.98	194.7	22.48	10.32	0.016601	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B48<173,$F$18*(173/B48),$F$18),2)	=((14.7-D48)*144*E48)+F48-G48-H48-I48	=$F$28	=IF((K48-J48)/(144*E48)>0,(K48-J48)/(144*E48),0)	=C48-14.7	=VLOOKUP(A48,$G$122:$K$153,2)
49	25118.98	194.7	22.47	10.32	0.016601	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B49<173,$F$18*(173/B49),$F$18),2)	=((14.7-D49)*144*E49)+F49-G49-H49-I49	=$F$28	=IF((K49-J49)/(144*E49)>0,(K49-J49)/(144*E49),0)	=C49-14.7	=VLOOKUP(A49,$G$122:$K$153,2)
50	30094.84	194.3	22.42	10.233	0.016599	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B50<173,$F$18*(173/B50),$F$18),2)	=((14.7-D50)*144*E50)+F50-G50-H50-I50	=$F$28	=IF((K50-J50)/(144*E50)>0,(K50-J50)/(144*E50),0)	=C50-14.7	=VLOOKUP(A50,$G$122:$K$153,2)
51	35084.81	193.7	22.33	10.104	0.016595	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B51<173,$F$18*(173/B51),$F$18),2)	=((14.7-D51)*144*E51)+F51-G51-H51-I51	=$F$28	=IF((K51-J51)/(144*E51)>0,(K51-J51)/(144*E51),0)	=C51-14.7	=VLOOKUP(A51,$G$122:$K$153,2)
52	40020.36	192.8	22.2	9.914	0.016589	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B52<173,$F$18*(173/B52),$F$18),2)	=((14.7-D52)*144*E52)+F52-G52-H52-I52	=$F$28	=IF((K52-J52)/(144*E52)>0,(K52-J52)/(144*E52),0)	=C52-14.7	=VLOOKUP(A52,$G$122:$K$153,2)
53	45837.23	191.8	22.01	9.644	0.016581	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B53<173,$F$18*(173/B53),$F$18),2)	=((14.7-D53)*144*E53)+F53-G53-H53-I53	=$F$28	=IF((K53-J53)/(144*E53)>0,(K53-J53)/(144*E53),0)	=C53-14.7	=VLOOKUP(A53,$G$122:$K$153,2)
54	49408.11	190.4	21.78	9.42	0.016574	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B54<173,$F$18*(173/B54),$F$18),2)	=((14.7-D54)*144*E54)+F54-G54-H54-I54	=$F$28	=IF((K54-J54)/(144*E54)>0,(K54-J54)/(144*E54),0)	=C54-14.7	=VLOOKUP(A54,$G$122:$K$153,2)
55	60850.54	187.2	21.21	8.794	0.016554	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B55<173,$F$18*(173/B55),$F$18),2)	=((14.7-D55)*144*E55)+F55-G55-H55-I55	=$F$28	=IF((K55-J55)/(144*E55)>0,(K55-J55)/(144*E55),0)	=C55-14.7	=VLOOKUP(A55,$G$122:$K$153,2)
56	70342.29	184.4	20.72	8.278	0.016536	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B56<173,$F$18*(173/B56),$F$18),2)	=((14.7-D56)*144*E56)+F56-G56-H56-I56	=$F$28	=IF((K56-J56)/(144*E56)>0,(K56-J56)/(144*E56),0)	=C56-14.7	=VLOOKUP(A56,$G$122:$K$153,2)
57	80342.29	181.8	20.28	7.816	0.01652	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B57<173,$F$18*(173/B57),$F$18),2)	=((14.7-D57)*144*E57)+F57-G57-H57-I57	=$F$28	=IF((K57-J57)/(144*E57)>0,(K57-J57)/(144*E57),0)	=C57-14.7	=VLOOKUP(A57,$G$122:$K$153,2)
58	90338.81	178.3	19.89	7.396	0.016505	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B58<173,$F$18*(173/B58),$F$18),2)	=((14.7-D58)*144*E58)+F58-G58-H58-I58	=$F$28	=IF((K58-J58)/(144*E58)>0,(K58-J58)/(144*E58),0)	=C58-14.7	=VLOOKUP(A58,$G$122:$K$153,2)
59	100339.8	176.8	19.62	6.964	0.01649	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B59<173,$F$18*(173/B59),$F$18),2)	=((14.7-D59)*144*E59)+F59-G59-H59-I59	=$F$28	=IF((K59-J59)/(144*E59)>0,(K59-J59)/(144*E59),0)	=C59-14.7	=VLOOKUP(A59,$G$122:$K$153,2)
60	110339.7	174.8	19.2	6.606	0.016478	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B60<173,$F$18*(173/B60),$F$18),2)	=((14.7-D60)*144*E60)+F60-G60-H60-I60	=$F$28	=IF((K60-J60)/(144*E60)>0,(K60-J60)/(144*E60),0)	=C60-14.7	=VLOOKUP(A60,$G$122:$K$153,2)
61	120305.8	173.2	18.93	6.447	0.016469	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B61<173,$F$18*(173/B61),$F$18),2)	=((14.7-D61)*144*E61)+F61-G61-H61-I61	=$F$28	=IF((K61-J61)/(144*E61)>0,(K61-J61)/(144*E61),0)	=C61-14.7	=VLOOKUP(A61,$G$122:$K$153,2)
62	130302	171.8	18.69	6.245	0.016461	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B62<173,$F$18*(173/B62),$F$18),2)	=((14.7-D62)*144*E62)+F62-G62-H62-I62	=$F$28	=IF((K62-J62)/(144*E62)>0,(K62-J62)/(144*E62),0)	=C62-14.7	=VLOOKUP(A62,$G$122:$K$153,2)
63	140302	170.4	18.47	6.048	0.016453	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B63<173,$F$18*(173/B63),$F$18),2)	=((14.7-D63)*144*E63)+F63-G63-H63-I63	=$F$28	=IF((K63-J63)/(144*E63)>0,(K63-J63)/(144*E63),0)	=C63-14.7	=VLOOKUP(A63,$G$122:$K$153,2)
64	150302	169.1	18.27	5.87	0.016446	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B64<173,$F$18*(173/B64),$F$18),2)	=((14.7-D64)*144*E64)+F64-G64-H64-I64	=$F$28	=IF((K64-J64)/(144*E64)>0,(K64-J64)/(144*E64),0)	=C64-14.7	=VLOOKUP(A64,$G$122:$K$153,2)
65	160302	167.8	18.07	5.696	0.016438	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B65<173,$F$18*(173/B65),$F$18),2)	=((14.7-D65)*144*E65)+F65-G65-H65-I65	=$F$28	=IF((K65-J65)/(144*E65)>0,(K65-J65)/(144*E65),0)	=C65-14.7	=VLOOKUP(A65,$G$122:$K$153,2)
66	170302	166.6	17.9	5.539	0.016431	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B66<173,$F$18*(173/B66),$F$18),2)	=((14.7-D66)*144*E66)+F66-G66-H66-I66	=$F$28	=IF((K66-J66)/(144*E66)>0,(K66-J66)/(144*E66),0)	=C66-14.7	=VLOOKUP(A66,$G$122:$K$153,2)
67	180302	165.3	17.72	5.374	0.016424	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B67<173,$F$18*(173/B67),$F$18),2)	=((14.7-D67)*144*E67)+F67-G67-H67-I67	=$F$28	=IF((K67-J67)/(144*E67)>0,(K67-J67)/(144*E67),0)	=C67-14.7	=VLOOKUP(A67,$G$122:$K$153,2)
68	190302	164.1	17.54	5.228	0.016417	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B68<173,$F$18*(173/B68),$F$18),2)	=((14.7-D68)*144*E68)+F68-G68-H68-I68	=$F$28	=IF((K68-J68)/(144*E68)>0,(K68-J68)/(144*E68),0)	=C68-14.7	=VLOOKUP(A68,$G$122:$K$153,2)
69	194052	163.6	17.47	5.164	0.016414	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B69<173,$F$18*(173/B69),$F$18),2)	=((14.7-D69)*144*E69)+F69-G69-H69-I69	=$F$28	=IF((K69-J69)/(144*E69)>0,(K69-J69)/(144*E69),0)	=C69-14.7	=VLOOKUP(A69,$G$122:$K$153,2)
70	196552	163.3	17.43	5.127	0.016413	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B70<173,$F$18*(173/B70),$F$18),2)	=((14.7-D70)*144*E70)+F70-G70-H70-I70	=$F$28	=IF((K70-J70)/(144*E70)>0,(K70-J70)/(144*E70),0)	=C70-14.7	=VLOOKUP(A70,$G$122:$K$153,2)
71	197802	163.2	17.41	5.116	0.016412	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B71<173,$F$18*(173/B71),$F$18),2)	=((14.7-D71)*144*E71)+F71-G71-H71-I71	=$F$28	=IF((K71-J71)/(144*E71)>0,(K71-J71)/(144*E71),0)	=C71-14.7	=VLOOKUP(A71,$G$122:$K$153,2)
72	203302	162.9	17.37	5.079	0.016411	=$F$25	=0.00000025*$F$9^2	=0.38*(($F$9/4000)^2)	=ROUND(IF(B72<173,$F$18*(173/B72),$F$18),2)	=((14.7-D72)*144*E72)+F72-G72-H72-I72	=$F$28	=IF((K72-J72)/(144*E72)>0,(K72-J72)/(144*E72),0)	=C72-14.7	=VLOOKUP(A72,$G$122:$K$153,2)

RHR - Long Term (After EPU) 1.5 wt. % Containment Leakage & 100% Spray Efficiency

Row	A Time (sec)	B OE Pool Temp (F)	C OE Pool Pressure psia	D Pg (psia)	E Vf (ft^3/lb)	F Z (ft)	G hf (ft)	H ha (ft)	I hd (ft)	J RHR NPSHa (ft)	K RHR NPSHr (ft)	L RHR OPR (psig)	M OPA (psig)	N OPC (psig)
78	785.6046	169.7	17.71	5.941	0.016449	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B78<173,$C$18*(173/B78),$C$18),2)	=((14.7-D78)*144*E78)+F78-G78-H78-I78	=$C$28	=IF(((K78-J78)/(144*E78))>0,((K78-J78)/(144*E78)),0)	=C78-14.7	=VLOOKUP(A78,$G$122:$K$153,2)
79	1097.896	171.8	17.84	6.245	0.016461	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B79<173,$C$18*(173/B79),$C$18),2)	=((14.7-D79)*144*E79)+F79-G79-H79-I79	=$C$28	=IF(((K79-J79)/(144*E79))>0,((K79-J79)/(144*E79)),0)	=C79-14.7	=VLOOKUP(A79,$G$122:$K$153,2)
80	2013.366	176.6	18.57	6.962	0.016488	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B80<173,$C$18*(173/B80),$C$18),2)	=((14.7-D80)*144*E80)+F80-G80-H80-I80	=$C$28	=IF(((K80-J80)/(144*E80))>0,((K80-J80)/(144*E80)),0)	=C80-14.7	=VLOOKUP(A80,$G$122:$K$153,2)
81	2982.323	180	18.17	7.611	0.016508	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B81<173,$C$18*(173/B81),$C$18),2)	=((14.7-D81)*144*E81)+F81-G81-H81-I81	=$C$28	=IF(((K81-J81)/(144*E81))>0,((K81-J81)/(144*E81)),0)	=C81-14.7	=VLOOKUP(A81,$G$122:$K$153,2)
82	4198.49	183.4	19.9	8.096	0.01653	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B82<173,$C$18*(173/B82),$C$18),2)	=((14.7-D82)*144*E82)+F82-G82-H82-I82	=$C$28	=IF(((K82-J82)/(144*E82))>0,((K82-J82)/(144*E82)),0)	=C82-14.7	=VLOOKUP(A82,$G$122:$K$153,2)
83	5126.042	185.2	20.34	8.42	0.016541	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B83<173,$C$18*(173/B83),$C$18),2)	=((14.7-D83)*144*E83)+F83-G83-H83-I83	=$C$28	=IF(((K83-J83)/(144*E83))>0,((K83-J83)/(144*E83)),0)	=C83-14.7	=VLOOKUP(A83,$G$122:$K$153,2)
84	6279.292	187	20.82	8.756	0.016552	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B84<173,$C$18*(173/B84),$C$18),2)	=((14.7-D84)*144*E84)+F84-G84-H84-I84	=$C$28	=IF(((K84-J84)/(144*E84))>0,((K84-J84)/(144*E84)),0)	=C84-14.7	=VLOOKUP(A84,$G$122:$K$153,2)
85	8036.636	189.1	21.6	9.161	0.016566	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B85<173,$C$18*(173/B85),$C$18),2)	=((14.7-D85)*144*E85)+F85-G85-H85-I85	=$C$28	=IF(((K85-J85)/(144*E85))>0,((K85-J85)/(144*E85)),0)	=C85-14.7	=VLOOKUP(A85,$G$122:$K$153,2)
86	10219.80	191	21.86	9.441	0.016578	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B86<173,$C$18*(173/B86),$C$18),2)	=((14.7-D86)*144*E86)+F86-G86-H86-I86	=$C$28	=IF(((K86-J86)/(144*E86))>0,((K86-J86)/(144*E86)),0)	=C86-14.7	=VLOOKUP(A86,$G$122:$K$153,2)
87	12083.87	192.2	22.06	9.786	0.016586	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B87<173,$C$18*(173/B87),$C$18),2)	=((14.7-D87)*144*E87)+F87-G87-H87-I87	=$C$28	=IF(((K87-J87)/(144*E87))>0,((K87-J87)/(144*E87)),0)	=C87-14.7	=VLOOKUP(A87,$G$122:$K$153,2)
88	15163.8	193.8	22.31	10.083	0.016594	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B88<173,$C$18*(173/B88),$C$18),2)	=((14.7-D88)*144*E88)+F88-G88-H88-I88	=$C$28	=IF(((K88-J88)/(144*E88))>0,((K88-J88)/(144*E88)),0)	=C88-14.7	=VLOOKUP(A88,$G$122:$K$153,2)
89	17880.2	194.3	22.43	10.233	0.016599	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B89<173,$C$18*(173/B89),$C$18),2)	=((14.7-D89)*144*E89)+F89-G89-H89-I89	=$C$28	=IF(((K89-J89)/(144*E89))>0,((K89-J89)/(144*E89)),0)	=C89-14.7	=VLOOKUP(A89,$G$122:$K$153,2)
90	20156.36	194.6	22.46	10.298	0.016601	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B90<173,$C$18*(173/B90),$C$18),2)	=((14.7-D90)*144*E90)+F90-G90-H90-I90	=$C$28	=IF(((K90-J90)/(144*E90))>0,((K90-J90)/(144*E90)),0)	=C90-14.7	=VLOOKUP(A90,$G$122:$K$153,2)
91	23811.7	194.7	22.48	10.32	0.016601	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B91<173,$C$18*(173/B91),$C$18),2)	=((14.7-D91)*144*E91)+F91-G91-H91-I91	=$C$28	=IF(((K91-J91)/(144*E91))>0,((K91-J91)/(144*E91)),0)	=C91-14.7	=VLOOKUP(A91,$G$122:$K$153,2)
92	24494.90	194.7	22.48	10.32	0.016601	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B92<173,$C$18*(173/B92),$C$18),2)	=((14.7-D92)*144*E92)+F92-G92-H92-I92	=$C$28	=IF(((K92-J92)/(144*E92))>0,((K92-J92)/(144*E92)),0)	=C92-14.7	=VLOOKUP(A92,$G$122:$K$153,2)
93	25119.98	194.7	22.47	10.32	0.016601	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B93<173,$C$18*(173/B93),$C$18),2)	=((14.7-D93)*144*E93)+F93-G93-H93-I93	=$C$28	=IF(((K93-J93)/(144*E93))>0,((K93-J93)/(144*E93)),0)	=C93-14.7	=VLOOKUP(A93,$G$122:$K$153,2)
94	30094.64	194.3	22.42	10.233	0.016599	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B94<173,$C$18*(173/B94),$C$18),2)	=((14.7-D94)*144*E94)+F94-G94-H94-I94	=$C$28	=IF(((K94-J94)/(144*E94))>0,((K94-J94)/(144*E94)),0)	=C94-14.7	=VLOOKUP(A94,$G$122:$K$153,2)
95	35064.61	193.7	22.33	10.104	0.016595	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B95<173,$C$18*(173/B95),$C$18),2)	=((14.7-D95)*144*E95)+F95-G95-H95-I95	=$C$28	=IF(((K95-J95)/(144*E95))>0,((K95-J95)/(144*E95)),0)	=C95-14.7	=VLOOKUP(A95,$G$122:$K$153,2)
96	40020.36	192.8	22.2	9.914	0.016588	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B96<173,$C$18*(173/B96),$C$18),2)	=((14.7-D96)*144*E96)+F96-G96-H96-I96	=$C$28	=IF(((K96-J96)/(144*E96))>0,((K96-J96)/(144*E96)),0)	=C96-14.7	=VLOOKUP(A96,$G$122:$K$153,2)
97	45637.23	191.8	22.01	9.644	0.016581	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B97<173,$C$18*(173/B97),$C$18),2)	=((14.7-D97)*144*E97)+F97-G97-H97-I97	=$C$28	=IF(((K97-J97)/(144*E97))>0,((K97-J97)/(144*E97)),0)	=C97-14.7	=VLOOKUP(A97,$G$122:$K$153,2)
98	49408.11	190.4	21.78	9.42	0.016574	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B98<173,$C$18*(173/B98),$C$18),2)	=((14.7-D98)*144*E98)+F98-G98-H98-I98	=$C$28	=IF(((K98-J98)/(144*E98))>0,((K98-J98)/(144*E98)),0)	=C98-14.7	=VLOOKUP(A98,$G$122:$K$153,2)
99	60650.64	187.2	21.21	8.794	0.016554	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B99<173,$C$18*(173/B99),$C$18),2)	=((14.7-D99)*144*E99)+F99-G99-H99-I99	=$C$28	=IF(((K99-J99)/(144*E99))>0,((K99-J99)/(144*E99)),0)	=C99-14.7	=VLOOKUP(A99,$G$122:$K$153,2)
100	70342.28	184.4	20.72	8.276	0.016536	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B100<173,$C$18*(173/B100),$C$18),2)	=((14.7-D100)*144*E100)+F100-G100-H100-I100	=$C$28	=IF(((K100-J100)/(144*E100))>0,((K100-J100)/(144*E100)),0)	=C100-14.7	=VLOOKUP(A100,$G$122:$K$153,2)
101	80342.28	181.8	20.26	7.818	0.01652	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B101<173,$C$18*(173/B101),$C$18),2)	=((14.7-D101)*144*E101)+F101-G101-H101-I101	=$C$28	=IF(((K101-J101)/(144*E101))>0,((K101-J101)/(144*E101)),0)	=C101-14.7	=VLOOKUP(A101,$G$122:$K$153,2)
102	90338.91	179.3	19.89	7.396	0.016505	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B102<173,$C$18*(173/B102),$C$18),2)	=((14.7-D102)*144*E102)+F102-G102-H102-I102	=$C$28	=IF(((K102-J102)/(144*E102))>0,((K102-J102)/(144*E102)),0)	=C102-14.7	=VLOOKUP(A102,$G$122:$K$153,2)
103	100339.9	176.8	19.67	6.984	0.01649	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B103<173,$C$18*(173/B103),$C$18),2)	=((14.7-D103)*144*E103)+F103-G103-H103-I103	=$C$28	=IF(((K103-J103)/(144*E103))>0,((K103-J103)/(144*E103)),0)	=C103-14.7	=VLOOKUP(A103,$G$122:$K$153,2)
104	110339.7	174.8	19.2	6.666	0.016478	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B104<173,$C$18*(173/B104),$C$18),2)	=((14.7-D104)*144*E104)+F104-G104-H104-I104	=$C$28	=IF(((K104-J104)/(144*E104))>0,((K104-J104)/(144*E104)),0)	=C104-14.7	=VLOOKUP(A104,$G$122:$K$153,2)
105	120306.5	173.2	18.93	6.447	0.016469	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B105<173,$C$18*(173/B105),$C$18),2)	=((14.7-D105)*144*E105)+F105-G105-H105-I105	=$C$28	=IF(((K105-J105)/(144*E105))>0,((K105-J105)/(144*E105)),0)	=C105-14.7	=VLOOKUP(A105,$G$122:$K$153,2)
106	130302	171.8	18.69	6.245	0.016461	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B106<173,$C$18*(173/B106),$C$18),2)	=((14.7-D106)*144*E106)+F106-G106-H106-I106	=$C$28	=IF(((K106-J106)/(144*E106))>0,((K106-J106)/(144*E106)),0)	=C106-14.7	=VLOOKUP(A106,$G$122:$K$153,2)
107	140302	170.4	18.47	6.048	0.016453	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B107<173,$C$18*(173/B107),$C$18),2)	=((14.7-D107)*144*E107)+F107-G107-H107-I107	=$C$28	=IF(((K107-J107)/(144*E107))>0,((K107-J107)/(144*E107)),0)	=C107-14.7	=VLOOKUP(A107,$G$122:$K$153,2)
108	150302	169.1	18.27	5.87	0.016445	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B108<173,$C$18*(173/B108),$C$18),2)	=((14.7-D108)*144*E108)+F108-G108-H108-I108	=$C$28	=IF(((K108-J108)/(144*E108))>0,((K108-J108)/(144*E108)),0)	=C108-14.7	=VLOOKUP(A108,$G$122:$K$153,2)
109	160302	167.8	18.07	5.696	0.016438	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B109<173,$C$18*(173/B109),$C$18),2)	=((14.7-D109)*144*E109)+F109-G109-H109-I109	=$C$28	=IF(((K109-J109)/(144*E109))>0,((K109-J109)/(144*E109)),0)	=C109-14.7	=VLOOKUP(A109,$G$122:$K$153,2)
110	170302	166.6	17.8	5.518	0.016431	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B110<173,$C$18*(173/B110),$C$18),2)	=((14.7-D110)*144*E110)+F110-G110-H110-I110	=$C$28	=IF(((K110-J110)/(144*E110))>0,((K110-J110)/(144*E110)),0)	=C110-14.7	=VLOOKUP(A110,$G$122:$K$153,2)
111	180302	165.3	17.72	5.374	0.016424	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B111<173,$C$18*(173/B111),$C$18),2)	=((14.7-D111)*144*E111)+F111-G111-H111-I111	=$C$28	=IF(((K111-J111)/(144*E111))>0,((K111-J111)/(144*E111)),0)	=C111-14.7	=VLOOKUP(A111,$G$122:$K$153,2)
112	190302	164.1	17.54	5.229	0.016417	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B112<173,$C$18*(173/B112),$C$18),2)	=((14.7-D112)*144*E112)+F112-G112-H112-I112	=$C$28	=IF(((K112-J112)/(144*E112))>0,((K112-J112)/(144*E112)),0)	=C112-14.7	=VLOOKUP(A112,$G$122:$K$153,2)
113	194052	163.6	17.47	5.164	0.016414	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B113<173,$C$18*(173/B113),$C$18),2)	=((14.7-D113)*144*E113)+F113-G113-H113-I113	=$C$28	=IF(((K113-J113)/(144*E113))>0,((K113-J113)/(144*E113)),0)	=C113-14.7	=VLOOKUP(A113,$G$122:$K$153,2)
114	196862	163.3	17.43	5.127	0.016413	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B114<173,$C$18*(173/B114),$C$18),2)	=((14.7-D114)*144*E114)+F114-G114-H114-I114	=$C$28	=IF(((K114-J114)/(144*E114))>0,((K114-J114)/(144*E114)),0)	=C114-14.7	=VLOOKUP(A114,$G$122:$K$153,2)
115	197602	163.2	17.41	5.115	0.016412	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B115<173,$C$18*(173/B115),$C$18),2)	=((14.7-D115)*144*E115)+F115-G115-H115-I115	=$C$28	=IF(((K115-J115)/(144*E115))>0,((K115-J115)/(144*E115)),0)	=C115-14.7	=VLOOKUP(A115,$G$122:$K$153,2)
116	200302	162.9	17.37	5.079	0.016411	=$C$25	=0.0000000477*$C$9^2	=$C$15	=ROUND(IF(B116<173,$C$18*(173/B116),$C$18),2)	=((14.7-D116)*144*E116)+F116-G116-H116-I116	=$C$28	=IF(((K116-J116)/(144*E116))>0,((K116-J116)/(144*E116)),0)	=C116-14.7	=VLOOKUP(A116,$G$122:$K$153,2)

GE Nuclear Energy

General Electric Company
175 Curtner Avenue, San Jose CA 95125

September 13, 2004		**Action Requested by:**	NA
GE-VYNPS-AEP-363		**Response to:**	Reference 3
DRF 0000-0007-5271		**Project Deliverable:**	NA
GE Proprietary Infomation			

cc: G. Paptzun
Y. C. Chu
B. Hobbs (ENOI)

To: Craig Nichols (ENOI)

From: Michael Dick

Author: Michael Dick

Subject: VYNPS Extended Power Uprate – ATWS Analysis Sensitivity to Condensate Storage Tank Water Temperature Change

References:

1. Entergy Nuclear Operations Inc., Vermont Yankee Nuclear Power Station, Asset Enhancement Program, GE Proposal No. 208-1JX8XA-HB1, Revision 5, dated November 13, 2002.
2. Entergy Nuclear Operations, Inc. Contract Order No. VY015144 (Asset Enhancement Program).
3. Letter PUPVY-04-445, dated September 9, 2004 "Evaluation of EPU ATWS Analysis (T0902) for CST Temperature of 135F"

Reference 3 requested GE to perform an evaluation of the sensitivity of the VYNPS ATWS analysis results to a change in CST temperature. The attachment to this letter provides the results of this evaluation.

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September 13, 2004

A signed copy of this letter is included in DRF 0000-0007-5271. Supporting technical information and evidence of verification for the attachment to this letter are contained in eDRF Section 0000-0032-4266.

MJD

Attachment

1. Vermont Yankee CST Temperature Increase for ATWS Events

ATTACHMENT 1

GE-VYNPS-AEP-363

Vermont Yankee CST Temperature Increase for ATWS Events

ATTACHMENT 9

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1.0 Task Objective

The object of this evaluation is to assess the impact of increased Condensation Storage Tank (CST) temperature on the ATWS evaluation for Extended Power Uprate (EPU) project. The original CST temperature used in the EPU analysis is 117°F (Reference 1). The ATWS analysis indicates that all acceptance criterion for reactor pressure vessel, peak cladding temperature (PCT), clad oxidation, suppression pool temperature and containment pressure are met. However, the CST temperature was subsequently determined to be 135°F (Reference 2). This evaluation is to provide justification to support that all the ATWS acceptance criterion can be met with the increased CST temperature.

2.0 Evaluation

The preferred high pressure make up water is drawn from CST and delivered to the reactor vessel through High Pressure Core Injection (HPCI) and Reactor Core Isolation Cooling (RCIC) systems after an isolation ATWS event. However, the initiation of the HPCI/RCIC flow starts after the peak vessel pressure and PCT have passed. The increase of CST temperature has no impact to these parameters and the clad oxidation. Therefore, the vessel and fuel integrity is not affected by the CST temperature change.

An increase of 18°F in CST temperature can reduce the core inlet subcooling. This causes an increase of the core voiding and the reactor power will decrease during the period when vessel water level is being controlled at Top of Active Fuel (TAF). The steam generation rate is reduced. However, the change in the CST temperature is small and only reduces the steam generation rate slightly. After the hot shutdown boron weight is injected into the vessel and the reactor has achieved hot shutdown, the decreased inlet subcooling allows more steam generation by the decay heat. Similarly, the change of steam generation rate is not significant. These two competing factors tend to cancel each other out. The net change in the peak suppression pool temperature with an 18°F increase in CST temperature is expected to be less than 0.5°F. Subsequently, the peak containment pressure should change no more than 0.2 psi. With a margin to suppression pool limit of more than 4°F (190°F vs 194.7°F limit) and an even larger containment pressure margin, the CST temperature increase poses no significant impact to the containment integrity during ATWS events.

In conclusion, an increase of 18°F for CST temperature in Vermont Yankee has insignificant impact to the ATWS events in EPU conditions.

3.0 References

1. GE-NE-0000-0016-3831-01, "Project Task Report, Entergy Nuclear Operations Incorporated, Vermont Yankee Nuclear Power Station, Extended Power Uprate, Task T0902 Anticipated Transients Without Scram", Rev. 0, July 2003.

2. Letter, C.J. Nichols to M. Dick, PUPVY-04-455, "Evaluation of EPU ATWS Analysis (T0902) for CST Temp of 135F," September 9, 2004.